Strawberry Production Guide

For the Northeast, Midwest, and Eastern Canada

2nd Edition

Strawberry Production Guide

For the Northeast, Midwest, and Eastern Canada

2nd Edition

Technical Editors
Kaitlyn Orde and Rebecca Sideman

Contributing Editors
Marvin Pritts and David Handley

Production & Design
Shyloh Favreau

University of New Hampshire Cooperative Extension

About This Guide

This guide is intended as a comprehensive resource for both novice and experienced strawberry growers in northeastern North America. It provides information on all aspects of strawberry culture. The second edition has been updated and revised throughout, and includes expanded and new information on variety selection (Ch. 3), production systems (Ch. 4), harvesting, handling and transportation (Ch. 12), marketing (Ch. 13) and budgeting/economics (Ch. 14). In addition, a new section on diagnosing problems in strawberry plantings has been added (Ch. 15).

Editions

This guide was first published in 1998 by the Northeast Regional Agricultural Engineering Service (NRAES) under publication NRAES-88; ISBN 0-935817-23-9.

The second edition is being published in 2023 by the University of New Hampshire Cooperative Extension under publication ISBN: 978-0-578-34891-9.

Funding

This material is based upon work supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, through the Northeast Sustainable Agriculture Research and Education (SARE) program under subaward number LNE20-403. USDA is an equal opportunity employer and service provider. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of SARE or the U.S. Department of Agriculture.

Disclaimer

Every effort has been made to make this an accurate resource. This text is intended as a guide and should be used in conjunction with other information sources on crop, soil, and farm management. The editors, authors, contributors, publishers, and funding agencies disclaim any liability, loss or risk (personal or otherwise) that occurs (directly or indirectly) as a consequence of the application of the information in this guide. Use of a product name does not imply endorsement of the product to the exclusion of others that may also be suitable, and exclusion does not imply a negative evaluation.

Citing this Guide

Orde, K. and B. Sideman (Eds.). 2023. Strawberry Production Guide for the Northeast, Midwest, and Eastern Canada. University of New Hampshire Cooperative Extension, Durham, NH.

Questions about the use of portions of this guide copyrighted by University of New Hampshire Cooperative Extension should be sent to: University of New Hampshire Extension, 59 College Road, Taylor Hall, Durham NH 03824, (603) 862-1520.

Authors

David Conner, Professor in the Department of Community Development and Applied Economics, University of Vermont (Chapters 13 and 14)

William Edwards, Professor Emeritus of Economics at Iowa State University (Chapter 14 and Downloadable Budget Workbook)

David Handley, Vegetable and Small Fruit Specialist and Extension Professor with the University of Maine (Chapters 1, 3, 4, 8 and 10)

George Hamilton, Fruit and Vegetable Field Specialist Emeritus with the University of New Hampshire Cooperative Extension (Chapter 11)

Elisabeth Hodgdon, Regional Vegetable Specialist with Cornell Cooperative Extension's Eastern New York Commercial Horticulture Program (Chapter 12 and Food Safety sections)

Laura McDermott, Berry Specialist with Cornell University Cooperative Extension based in eastern New York State (Chapter 6)

Kaitlyn Orde, Agricultural Scientist at the University of New Hampshire (Introduction; Chapters 4, 5, 12, 13, 14, and the Downloadable Budget Workbook)

Marvin Pritts, Professor of Horticulture in the School of Integrative Plant Science, Cornell University (Introduction; Chapters 1, 2, 4, 7, 15 and 16)

Rebecca Sideman, Extension Professor and Specialist at the University of New Hampshire (Introduction; Chapters 5, 11 and 16)

Alicyn Smart, Assistant Extension Professor and Director of the Plant Disease Diagnostic Laboratory at the University of Maine (Chapter 9)

Christopher Watkins, Director of Cornell Cooperative Extension, Associate Dean of Cornell University's College of Agriculture and Life Sciences, and College of Human Ecology, as well as a Professor in Cornell's School of Integrative Plant Science, Horticulture Section (Chapter 12)

Acknowledgements

The editors would like to thank Shyloh Favreau, University of New Hampshire Cooperative Extension, for the design, layout, and production of this guide. We also wish to thank Claire Whitehouse, University of Vermont, for thoughtful reviews and copyediting of the chapters in this guide.

We thank the following individuals for their contributions to, and reviews of, various chapters: Chris Callahan, University of Vermont (Chapter 12); Kathleen Demchak, The Pennsylvania State University (Chapter 4); Mykala Robertson, Cornell University (Chapter 1) and Lindsey Pashow, Cornell Cooperative Extension (Chapter 13 and 14).

We are grateful to the following individuals who contributed to the first edition: Marvin Pritts, David Handley, Bertie Boyce, Daniel Cooley, Donald Daum, Alison DeMarree, Richard Derksen, James Dill, Joseph Fiola, Barbara Goulart, James Hancock, Kevin Maloney, Regina Rieckenberg, Sonia Schloemann, Cathleen

Table of Contents

Authors iii

Acknowledgments iv

Getting Started 1

An Invitation to Join 2

Introduction 3

Chapter 1.
The History and Biology of the Cultivated Strawberry 4

Chapter 2.
Site Selection and Preparation 9

Chapter 3.
Variety Selection 16

Chapter 4.
Production Systems 20

Chapter 5.
Temperature Regulation: Mulches, Rowcovers, Frost Protection, and Evaporative Cooling 49

Chapter 6.
Water Management 58

Chapter 7.
Soil and Nutrient Management 72

Chapter 8.
Insect, Mite, Mollusc, and Vertebrate Scouting and Management 91

Chapter 9.
Disease Management and Physiological Disorders 111

Chapter 10.
Weed Management 125

Chapter 11.
Spray Application Technology 134

Chapter 12.
Harvesting, Handling, and Transporting Fresh Fruit 149

Chapter 13.
Sales & Marketing 159

Chapter 14.
Budgeting & Costs 173

Chapter 15.
Diagnosing Problems in Strawberry 192

Chapter 16.
Questions and Answers about Pesticide Residues, Organic Production, and Strawberries 195

Getting Started

Growing strawberries is not easy. To succeed, you must be a good horticulturist, pest, disease, and weed manager, have a reliable and competent staff of farm workers, and a market for fruit. Below are some questions to consider before embarking in the strawberry business. Information in this guide will help you answer the questions.

1. Have you checked local ordinances regarding zoning, parking, signs, noise, riparian rights, etc., to see if they might conflict with your plans for berry production?

2. How do you plan to market the fruit? Have you evaluated your farm's location in relation to population centers, off-road parking, visibility, and competition? Will customers be able to find your farm easily?

3. Are your facilities adequate for the sales approach you plan to use? Do you have cooling and storage facilities? Is there enough acreage and labor to pick daily?

4. Do you have sufficient capital resources to invest in establishing the crop and maintaining it for up to a year before it produces a crop? Keep in mind that a return on investment may be several years away.

5. Do you have equipment for plowing, harrowing, spreading fertilizer, laying beds, cultivating, pumping and running irrigation, spraying for pests/pathogens/weeds, and harvesting?

6. Do you have the necessary licenses to apply pesticides?

7. Is the soil in your area appropriate for growing strawberry? Is the soil sufficiently drained? Can it be amended to support berry production?

8. Do you have a large enough water supply for irrigation and frost protection?

9. Does your land slope enough to allow for air drainage, but not so much that it is difficult to work?

10. Where will you obtain labor during the busy picking season? Management, harvest, and customer-facing labor should be considered. How are your people management skills?

11. Are you set up to keep track of input expenses, payroll, pesticide applications, employee records, yield records, and perhaps customer mailing lists?

12. Do you have land for future expansion and crop rotation?

13. Have you acquired reference resources and a support network? Consider becoming a member of state and national grower organizations—for example, the North American Strawberry Growers Association.

An Invitation to Join

The North American Strawberry Growers Association (NASGA) was organized in 1977 and incorporated as a non-profit corporation by progressive strawberry growers and leading small fruit researchers.

Their purpose is to support USDA and state/provincial research programs, develop educational seminars and publications, promote development of equipment, varieties, and cultural methods to improve efficiency for the strawberry industry—including grower applied research, and promote beneficial legislation.

If you grow and market strawberries and other small fruits, educate or consult, or are exploring the myriad dimensions of small fruit growing as a career, then it is time to recognize that the North American Strawberry Growers Association is a valuable key to your success! NASGA represents more than **200 members in 40 states, 10 provinces of Canada and 15 countries.** NASGA continues to be a grower-based association strongly rooted in the original philosophy that ongoing research will provide knowledge to strengthen and improve strawberry production and marketing.

Benefits of membership to the North American Strawberry Growers Association

- 25% of membership dues collected is invested in research through the North American Strawberry Growers Research Foundation. The Foundation has historically provided $40,000–$50,000 annually in funding for strawberry research.
- Four newsletters a year filled with research findings, new production methods and new marketing techniques.
- Reduced rates for participating in NASGA conferences as well as Summer and International tours.
- Access to the top strawberry researchers and horticulturists in the United States and Canada. At our three-day annual meeting held in the winter, there is ample time to speak directly with scientists and professionals who are vitally interested in your concerns.
- New ideas developed by other growers. A true sign of a successful grower is a willingness to share knowledge gained from personal successes and failures. Such sharing is a major component of our annual meeting.
- **Networking!** Many lifetime friendships have been forged amongst members who talk regularly and share advice.

We invite you to join or continue your membership with NASGA and take advantage of new experiences and friendships while strengthening the solid foundation of information needed to be a successful grower. For information on becoming a member please visit www.nasga.org or contact the NASGA office at 905-735-5379 info@nasga.org

North American Strawberry Growers Association

Introduction

The cultivated strawberry, *Fragaria ananassa* Duch., is a relative newcomer to agriculture. The varieties now grown in most parts of the world are derived from hybrids developed within the last 200 years. The fruit of these varieties is quite different from that of the natural ancestral species that were harvested until the early 1800s.

The strawberry has become the basis of a large commercial industry and is one of the most popular small fruits in the United States. Annual per capita consumption of fresh strawberries is nearly 8 lbs/p.p., and growing. Most strawberry fruit produced in the United States are grown as annuals in California and Florida and sold through the wholesale market, primarily to supermarkets. These two states supply much of the U.S. market using varieties that bear fruit that can survive long-distance shipping.

In the Northeast and Midwest, a market exists for locally produced strawberries for fresh consumption. In these regions, the focus is typically eating quality, not shelf-life or shipping durability. Few farms grow strawberries exclusively—most strawberry growers produce other fruits and vegetables because the strawberry season can be very short. However, there are methods and plant types that can be used to extend the fruiting season (see Chapter 4).

Many strawberry varieties are resistant to soil and leaf diseases, and tolerate a wide range of soil types. Short-day varieties ("June-bearers") typically ripen over a 3–5-week period beginning in late May to mid-June, depending on the location. Day-neutral varieties may begin fruiting earlier than this (if overwintered or planted very early) or by mid-July (if planted in the spring), and will continue fruiting into the fall.

Historically, in eastern Canada and the Northeast and Midwest, strawberries have been grown as perennials and fruited for several years before being replaced with new plantings. This was due to widespread use of the matted row production system, which uses straw and relies on runner production. In recent years, plasticulture production has gained in popularity, especially for growers looking for improved weed control, soil drainage, or modify soil temperatures. Not all varieties are well-suited for plasticulture, as runners are removed in this system, and some classic short-day varieties are prolific runner producers.

Other mulching approaches, such as biodegradable mulch and "hybrid" systems (plasticulture converted to matted row), can be found throughout the Northeast, Midwest, and eastern Canada. In fact, there is great diversity in production system among farms in these regions, as well as a strong culture of adapting practices to individual farms.

Plant type (dormant, plug, waiting bed, etc.) is an area where there is likely to be significant change in the coming years, especially if plasticulture continues to become more widespread. Runner removal from spring-planted dormant crowns is labor-intensive, time-consuming, and costly for growers, but late summer-planted plugs may help to reduce these inputs. Other systems may be used to shorten the time between planting and harvest.

In the coming decades, we also expect to see breeding efforts focus on developing varieties for specific environments and systems, such as protected culture, hydroponic, organic systems, plasticulture and regional adaptability. This may be hastened by an increasing number of non-traditional strawberry producers in North America that utilize highly controlled environments and hydroponic systems.

CHAPTER 1

The History and Biology of the Cultivated Strawberry

A Brief History

The exact origin of the modern cultivated strawberry, *Fragaria x ananassa* Duch., is unclear, but the best evidence indicates that it was derived from a cross between two American species, *Fragaria virginiana* Duch. and *Fragaria chiloensis* Linn., made in France in the 1700s. The former species is a common inhabitant of the eastern coast of North America where it was used extensively by indigenous people, and continues to be part of Iroquois culture today. Sixteenth-century colonists were greatly impressed by its size and flavor. This species produced larger fruits than the common wild strawberry of Europe (*F. vesca*). The larger fruit size was due, in part, to the 8 sets of chromosomes in this species, compared to 2 sets in *F. vesca*. Roger Williams, founder of Rhode Island, reported in 1643 that "the English have exceeded and make good strawberry wine." The species was introduced in England and became a favorite there in local gardens.

In 1712, while gathering information for the French navy about Spanish fortifications along the west coast of South America, Captain Amedee Frezier was struck by the large-fruited strawberries cultivated there by indigenous Mapuche peoples. Being an amateur botanist as well as a spy, he collected some plants for the voyage home. Two of the few specimens that survived the journey were given to the Royal Garden in Paris, along with the statement that they bore fruit "as big as walnuts." Antonine de Jussieu, director of the garden at the time, must have been disappointed, then, when the plants produced only a few small, deformed berries.

The plants Frezier had collected were *F. chiloensis*, another species with 8 sets of chromosomes. This species is mostly dioecious (having male and female plants), and he had collected only females (since it was only female plants that bore fruit). Without male plants to produce pollen, fruits would not develop properly. Fortunately, the species was retained in some collections and later redeemed when, in Brittany, it was discovered that interplanting it with *F. virginiana*, a plentiful pollen producer, resulted in excellent crops. *F. chiloensis* soon became the major species of commerce, although, despite its impressive size, the strawberry was pale, seedy, and faint of flavor.

Seedlings of *F. chiloensis* and *F. virginiana* crosses began to appear in European gardens. Some of the progeny bore even larger fruit than *F. chiloensis* and had a deep red flesh. The flavor was somewhat reminiscent of pineapple, and for this reason the plant became known as the pineapple strawberry. The origin of this strawberry was initially shrouded in secrecy, probably by businesspeople hoping to earn high profits. But in 1766, Antoine Nicholas Duchesne published a hypothesis on its hybrid origin based on his experience with strawberry breeding and knowledge of the Brittany practices.

The pineapple strawberry was named *Fragaria x ananassa* Duch. Crosses and selections between *F. chiloensis* and *F. virginiana* continued, and breeding among the progeny commenced as well. Eventually, selections from these crosses would lead to strawberries similar to those grown today—large, red fruit with exceptional flavor.

In America, the early commercial strawberry industry was dependent upon the European introductions of *F. virginiana* and *F. x ananassa*. However, in 1838, Charles Hovey of Cambridge, Massachusetts introduced the 'Hovey' strawberry.

This variety was the result of crossing a European pineapple strawberry with a native *F. virginiana* plant. 'Hovey' is credited as being the first variety of any fruit made from an artificial cross in the United States. The exceptional quality of both the fruit and the plant stimulated a great new interest in strawberries throughout the country. 'Hovey' and later U.S. introductions, such as 'Wilson' and 'Howard,' provided the basis for future breeding programs.

Many important varieties have been released over the past 150 years from breeding programs throughout North America. These programs have contributed varieties with regional adaptation, as well as outstanding characteristics such as size, firmness, red stele resistance, and day-neutrality (the ability to initiate flowers over a wide range of day lengths). Day-neutral varieties afford growers the opportunity to greatly extend the harvest season and are responsible for the expansion of the California strawberry industry to nearly year around production. Interestingly, varieties developed in one geographic area tend not to do well in other locations. For example, European varieties are not commonly grown in North America. An exception are the day-neutral varieties from California that tend to perform well in many locations.

The hybrid nature of the cultivated strawberry provides breeders with the genetic variability to make substantial, consistent progress, and vast native populations still exist that exhibit useful horticultural traits. Plant breeders will likely make much more progress in the ensuing decades. Surely, many new delectable varieties are on the horizon.

Growth and Development of the Strawberry Plant

A strawberry plant consists of a **crown** from which leaves, flowers, runners (stolons), branch crowns, and adventitious roots grow (figure 1-1). The **leaves** are arranged spirally, such that every sixth leaf is above the first. Each leaf has 3 leaflets with a thick cuticle layer. Stomata appear only on the leaf undersides. Each leaf lives for about 6 months before senescing. Leaves produced in spring and early summer die after exposure to hard frosts in the fall and are replaced by new leaves in the spring. Leaves produced late in the season overwinter until the following spring. Winter leaves have the ability to photosynthesize when light is available and temperatures are not too cold.

An **axillary bud** is produced at the base of each leaf and may develop into a runner or branch crown, or remain dormant, depending upon environmental conditions. **Runner** development is stimulated by long days and warm temperatures. Runner plants are the primary means of propagating strawberries commercially. To propagate strawberries, runners that have rooted over the summer are dug between late fall and early spring and stored in coolers at about 32˚F until spring planting. This is the most common method of propagation.

Plants also can be propagated by rooting runner tips. Runner tips are removed in early summer and placed into plug trays, where they are misted until they root. These are called "plug plants" in the industry and are used primarily for fall planting in the annual plasticulture system (see Chapter 4 for details on plug production).

Branch crown development is promoted by short days and thus tends to occur late in the season. Being a very reduced stem with spirally arranged leaves, a branch crown has much of the same anatomy as the main crown. At one time, strawberry varieties that characteristically produced few runners were propagated by branch crowns. Whole plants would be dug in the fall, and the numerous branch crowns would be divided and stored for spring planting. This practice is labor intensive, however, and is not widely used today.

Adventitious roots arise from the crown and runner plant primarily in late summer and fall. They extend several inches into the soil and form numerous lateral roots, which are the primary means of water and nutrient absorption. Fine roots are constantly being produced on the lateral roots. Primary (adventitious) roots may live 2–3 years; lateral roots usually live 1 or 2 years. The largest concentration of roots occurs in the upper 6 inches of the soil. The length and number of roots formed depend on soil conditions and plant density. Typically, each plant maintains 20–30 primary roots, the average root length being 4–6 inches. Only after the development of numerous lateral roots on runner plants (which is encouraged by proper soil moisture conditions) can they become independent of the mother plant—that is, survive without support from the connecting stolon.

The onset of cooler weather and shorter days promotes starch accumulation in the roots and crowns. This starch is gradually depleted over the winter to ensure plant survival until the onset of photosynthesis in the spring. Plants that do not accumulate sufficient starch may not survive the winter.

Each strawberry variety initiates **flower buds** after exposure to a unique combination of day length and temperature. Most varieties begin flower bud initiation under conditions of shortening days and cool temperatures, which occur naturally in late September and October in the Northeast; such varieties are called **short-day**, or **June-bearing**, strawberries. Some varieties are not sensitive to day length and will initiate flower buds when temperatures are neither too hot nor too cold (between 40– 85˚F); these varieties are called **day-neutrals**. Other varieties fall between these 2 extremes and exhibit a weak response to day length.

Those who work with strawberries have struggled to properly describe these variants. Terms such as **everbearing**, **day-neutral**, **long-day, remontant** and **repeat-flowering** have been used. For the purposes of this guide, the term "day-neutral" will be used to include all of the aforementioned types since this terminology is currently used by the nursery industry.

In the Northeast, flower bud initiation in short-day types is completed by November, but flowering does not occur until spring. In day-neutral types, flowering occurs about 6 weeks after bud initiation, which occurs continuously from late spring through fall.

Strawberries typically require about 200–300 hours of chilling temperatures (40–50˚F) after flower bud initiation to break dormancy and reinvigorate the plant. Accumulating this much chilling is not an issue in most strawberry-growing regions, but can be insufficient in regions of California or Florida. In these warmer areas, planting stock is first grown in cooler regions before being transplanted to production regions, and/or is given artificial chilling before transplanting.

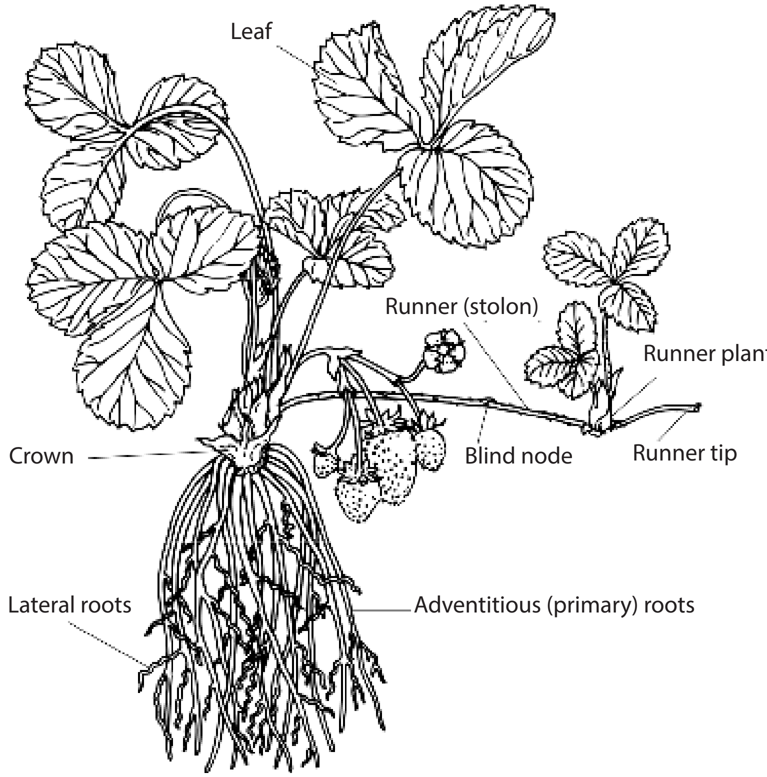


Figure 1-1. Parts of the strawberry plant.

Flower Cluster and Fruit Development

The strawberry **flower cluster,** or **inflorescence** (figure 1-2), is a modified stem terminated by a primary blossom. Branches arise at nodes from buds in the axils of modified leaves, or bracts. Each branch is terminated by a blossom. Typically, 2 secondaries, 4 tertiaries, and up to 8 quaternaries follow the primary blossom, which is sometimes referred to as the king—or queen—blossom.

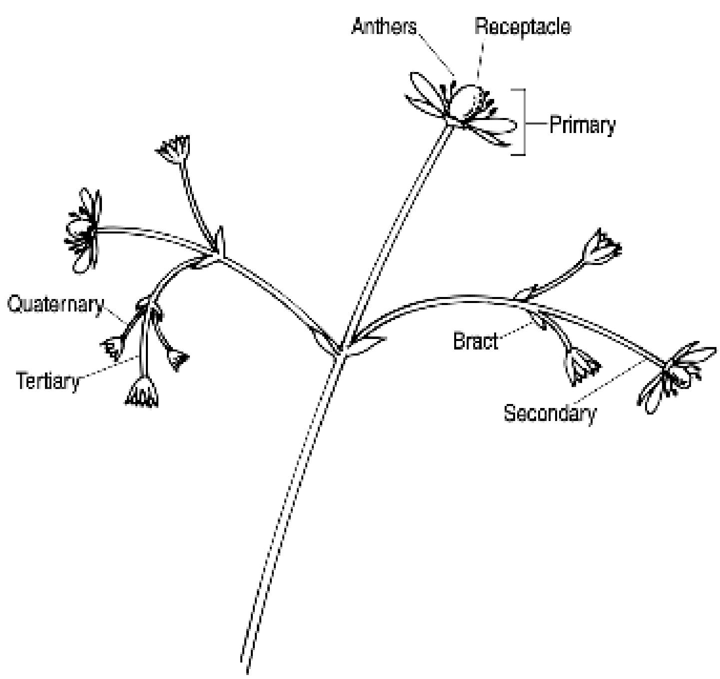


Figure 1-2. The strawberry inflorescence.

An individual flower typically has 10 green sepals, 5 white petals, and 20–35 stamens arranged in a spiral pattern in 3 whorls. The pistils are arranged spirally on the receptacle and number anywhere from 60–600. Pistils occur in the greatest numbers on the primary blossom, and their numbers decrease successively down the inflorescence. Ornamental strawberries may produce pink or red-colored petals.

Strawberries can partially self-fertilize since both male and female gametes are present on an individual flower, though fruit set, yield, and quality are all improved if the flower is insect-pollinated. This could be due to several factors including genetic outcrossing and abundant pollen distribution to the stigmata provided by multiple pollinator visits. Some varieties are able to self-pollinate better than others. Stigmas remain receptive to pollen for 8–10 days, and fertilization occurs 24–48 hours after pollination.

In the past, honey bee (*Apis millifera*) was recognized as the main insect pollinator of strawberry. However, strawberry flowers do not appear to be that attractive to honey bees, and they are more likely to be pollinated by other species of wild bees. In a recent study in upstate NY, many native bees and other insects like wasps, flies, butterflies, moths, and beetles (orders Hymenoptera, Lepidoptera, Diptera, and Coleoptera) were observed visiting strawberry flowers, with visitor diversity shifting over the season. In that study, the main pollinators of strawberry were native sweat bees (*Halictus confusus*) in the early growing season and small black sweat bees (*Lasioglossum* spp.) later on.

The strawberry fruit is not a true berry, despite its name. A true berry develops from the ovary of a flower, whereas the strawberry develops from the flower receptacle. The ovaries are contained in the achenes (seeds) that are on the outside of the fruit, so these dry seeds are the real fruits.

Cell division accounts for only 15–20% of total fruit growth and occurs mostly before anthesis (anthesis marks the shedding of pollen from the anthers). Approximately 80% of subsequent growth is from cell enlargement. Sugars, aromatic compounds, and pigments all increase as the receptacle tissue matures. Ripening, from anthesis to harvest stage, lasts approximately 30 days, depending on environmental conditions. The strawberry fruit is sensitive to temperature as it develops. Warm temperatures prior to and just after flowering accelerate development, but warm to hot temperatures near ripening will reduce the sugar content of fruit. This reduction can be significant if temperatures are greater than 80˚F near ripening. Environmental conditions that favor the highest sugar accumulation in fruit are warm days and cool nights.

Development of the receptacle is controlled by growth regulators, primarily auxins, which are synthesized in the achenes. Auxin, which is produced in the endosperm and translocated into the receptacle tissues, stimulates growth via cell enlargement. Removal of achenes after fertilization results in a proportionate reduction in fruit expansion. For example, leaving only 3 achenes on a receptacle results in three areas of growth directly below and surrounding those achenes. A ring of achenes left on a receptacle results in a ring of growth. This is why insect or frost damage to the ovaries or small achenes causes deformities in fruit. The ultimate size and shape of a strawberry are thus a function of the number of achenes on the receptacle, the area of receptacle tissue surrounding each achene, and the distribution of the achenes on the receptacle. Receptacles with few achenes will be small, as is observed for those receptacles lowest on the inflorescence. Fruit with more receptacle growth per achene will be larger. The location of the achenes on the receptacle will affect the distribution of growth and, therefore, berry shape. This is mainly under genetic control. It is sometimes possible to identify a strawberry variety by its shape alone. Figure 1-3 below shows the types of berry shapes.

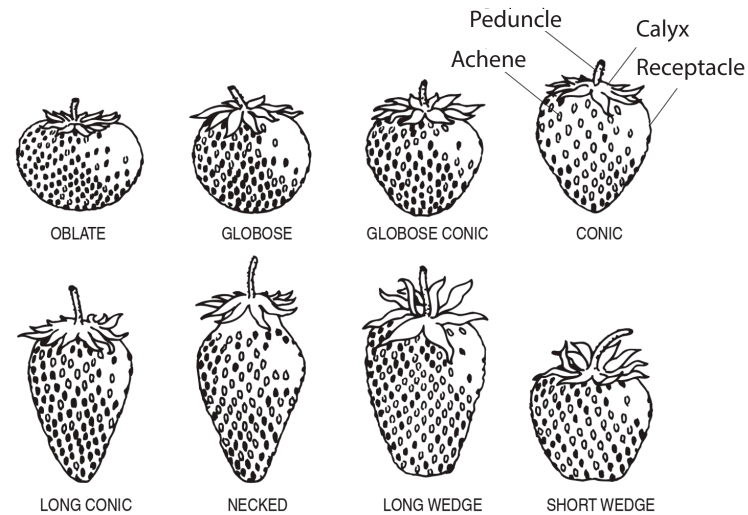


Figure 1-3. Strawberry shapes.

Harvested fruit that is not fully ripe will continue to color, even though sugar content will not increase after harvest. This is why fruit that has been in transit for several days may look fully ripe, but is not as sweet as the color would indicate.

Much progress has been made in understanding the evolutionary origins of strawberry and in sequencing the genomes that comprise the octoploid species. This knowledge enables breeders to develop improved breeding strategies and more efficiently select for desirable traits. While much of the world's breeding efforts have focused on yield, size, firmness, regional adaptation, and season extension, the focus in the future will be on enhanced consumer traits such as flavor (sugar, acid, aromas, phenolics) and more sustainable production practices.

Further Reading & Citations

Dale, Adam and James L. Luby, ed. *The Strawberry into the 20th Century: Proceedings of the Third North American Strawberry Conference.* Portland, Oregon: Timber Press, 1991.

Darrow, G. M. *The Strawberry.* New York: Holt, Rinehart, and Winston, 1966.

Galletta, Gene J. and David G. Himelrick. *Small Fruit Crop Management.* Englewood Cliffs, New Jersey: Prentice-Hall, 1990.

CHAPTER 2

Site Selection and Preparation

Site Selection

Site selection is a major consideration for strawberry production. The site will affect not only yield potential but also marketing options. Pick-your-own (PYO) marketing is common in the Northeast and Midwest. PYO operations close to a major highway or population center have the best chance for success. If the site is ideally located for PYO, keep in mind that not all of the land can be planted in berries—some must be reserved for customer parking and crop rotation. If berries will be sold through retail outlets, then production fields should be close to the outlets to minimize the time strawberries will be in transit. Otherwise, a refrigerated truck may be necessary to keep fruit cool during transit. The roads between the production fields and the retail outlet should be mostly paved to ensure a smooth ride.

Typically, the highest productivity from a strawberry planting is in its first fruiting year on a site that has never been used for strawberry production. The longer the time between crops of strawberry, the better they will likely perform. Do not grow strawberries for 5 or more consecutive years on the same site without some type of crop rotation. Productivity usually declines after the first fruiting year, and by year 5, yields can be quite low. Plan to reserve at least 30% of land (preferably 50–70%) for rotation in future years because a minimum of 3 years should elapse between plantings on the same site. Land not planted in strawberries should be planted in soil-improving cover crops or cash crops that allow for easy weed management.

When selecting a new site for planting, or when rotating with cover crops, pay attention to the historic herbicide use patterns. Herbicides used on many crops, especially grains, can be toxic to strawberries. If in doubt about the residual herbicidal activity in a proposed site, take a jar of soil from that site, and similar soil from a site that never had herbicides applied. Plant some bean, cucumber and corn seeds in the two jars. Compare their growth after germination. If the seedlings are stunted in the soil from the proposed site, then it may be best to delay planting there until the herbicide has dissipated.

Another major consideration for site selection is the availability of water. Strawberries need a lot of water for both irrigation (see Chapter 6) and frost protection (see Chapter 5). For successful berry production, the site must have access to an ample supply of high-quality water (sediments, nutrients, bacteria and algae, low in salts—less than 1.0 mS/cm electrical conductivity is best).

Equally important as having available water is having good internal soil water drainage. Strawberries cannot tolerate standing water or the diseases that thrive in wet conditions. If the site is too wet for strawberry production, install subsoil drainage or plant on raised beds.

In general, strawberries are tolerant of a wide range of soil types and conditions. In most locations, the ideal soil for strawberry production is a well-drained, sandy loam with a pH of 6.0–6.5. Drainage and soil pH can be modified on less-than-ideal soils. In acidic, sandy soils or on calcareous soils, certain micronutrients can be deficient, so lime or sulfur may be required to adjust pH levels. Heavy clays should be avoided, but sandy soils are acceptable. Planting and cultivating strawberries are difficult in stony soils, and such soil is hard on equipment. In general, sites that produce good alfalfa crops tend to be good for strawberries.

Avoid steep slopes (greater than 5%), because they are erodible and difficult to cultivate and irrigate uniformly. Moderate slopes (3–5%) allow air to drain and, therefore, reduce the risk of frost injury. South-facing slopes tend to increase the risk of frost injury in spring because plants generally bloom earlier, and west-facing slopes present the greatest risk for winter injury because they are exposed to persistent, desiccating winds in winter.

For most varieties, strawberry crowns can be injured when their temperature approaches 20˚F, so avoid planting in frost pockets where cold air accumulates. Hardier varieties exist that can tolerate colder temperatures, but with adequate mulching, damage usually does not occur. Open flowers are damaged at 28–30˚F—avoid planting in frost pockets where cold air accumulates.

Site Preparation

Weeds

A major step in site preparation is eliminating perennial weeds. Weeds cause more economic loss than diseases and insects combined. Weeds also encourage the establishment of pest populations and interfere with harvest. Eliminating weeds the year before planting is much easier than controlling them after planting: few herbicides are labeled for use in strawberries, and these herbicides have a limited effect on perennial weeds. Therefore, the time to control these weeds is before the strawberries are planted. Too many growers plant directly into a site where perennial weeds were not eliminated the previous summer, and then spend the next several years trying to find the right combination of herbicides to undo the damage. Starting site preparation 2–3 years in advance will be rewarded in future years.

Rotation, coupled with the use of a broad-spectrum post-emergent herbicide the summer before planting, is an effective approach to eliminating weeds. Cover cropping the site again after applying herbicide will further suppress weed growth. Repeated cultivation or covering a site with a black plastic tarp for several months is also effective for smaller plantings. Beginning site preparation 2–3 years before planting is especially important if the strawberries are going to be grown organically. Without good site preparation, many hours will be required to remove weeds by hand.

Fumigation at high rates will suppress weeds, although its use worldwide is diminishing because of environmental concerns, availability, and expense. In some situations, nematodes, soil diseases, soil insects, or intense weed pressure may justify fumigation. For fumigation to work properly, the soil should be friable, warm (greater than 50˚F), and devoid of decomposing plant material. The best time to fumigate a strawberry field is late summer or early fall of the year prior to planting. Chapter 10 provides more details on weed management.

A few preëmergent herbicides are labeled for use 30 days before planting. The herbicide is applied to bare ground and then the strawberries are transplanted without disturbing the soil.

Steam sterilization is a non-fumigant alternative for killing soil pathogens (bacteria, viruses, fungi), weed seeds, and nematodes. Both surface and deep soil methods exist, which vary in their efficiency. Soil steaming has been used successfully in high tunnels and research has found it can be as effective as chemical fumigation. Equipment costs can be high; soil steamers suitable for small areas are available for rent through some conservation district farm equipment rental programs.

Nutrient Amendments

Before planting, test the soil for pH, potassium, phosphorus, magnesium, calcium, and boron. Sample soil in a V-shaped pattern within the field (figure 2-1), and collect from at least 10 locations per acre. The sample should represent the profile of the top 10–12 inches of soil. After testing, plow the site, add the amount of nutrients recommended by the soil-testing laboratory, and then disc. Because soil-testing procedures are not standardized, follow the recommendations from the laboratory where the samples were analyzed. Do not use test results from one laboratory and sufficiency ranges from another. It takes 1 year for lime to raise soil pH and for sulfur to lower soil pH to the desired level, so these amendments must be applied 1 year before planting. The more finely ground the sulfur or lime, the faster it will react with the soil. The soil must also be warm and moist for the change in pH to occur.

To increase soil pH, amend with calcite or dolomitic lime. Liming agents differ from one another in 2 important ways, both of which will influence their effectiveness: (1) chemical composition, which affects acid-neutralizing potential and fertilizer value, and (2) particle size, which determines liming efficiency and ease of application. Consider the relative importance of these when selecting a liming agent. For example, even though dolomite has a lower neutralizing value than calcite, it provides supplemental magnesium. Moreover, finely ground lime is more difficult to apply than coarser particles, but it changes the soil pH more quickly.

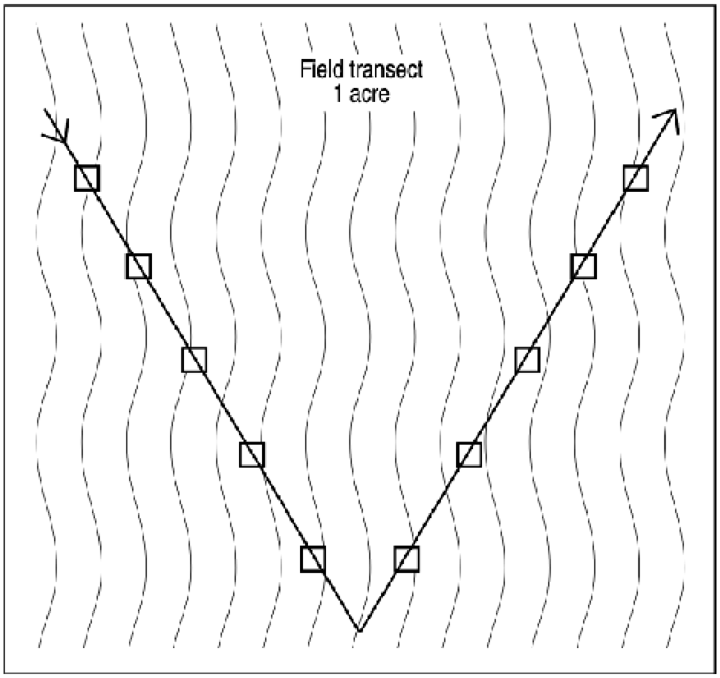


Figure 2-1. "V" pattern used for sampling a field.

Sulfur lowers soil pH as bacteria convert elemental sulfur into sulfuric acid. Sulfur comes as a wettable powder or as prills, with the former reacting faster to lower the soil pH. Aluminum sulfate is sometimes recommended for acidification because it provides an already oxidized form of sulfur; but it is expensive, and 6 times as much is required to do the same job as powdered sulfur. Also, aluminum toxicity can occur when large amounts of aluminum sulfate are used, so it is not recommended.

Certain nutrients, like phosphorus, are very insoluble in water and move very slowly through the soil. It may take years for phosphorus applied to the soil surface to reach the root zone of the plant and be taken up. For this reason, it is imperative to apply sufficient phosphorus before planting and to mix it into the root zone. Chapter 7 provides more details on nutrient management.

Animal manures and legumes offer a good source of slowly released nitrogen when they are incorporated into the soil prior to planting. Animal manures are a potential source of weed seeds and might provide too much phosphorus, so use care when applying. Manure applied to fields should be well-composted and worked into the soil prior to planting to minimize any risk of fruit contamination from pathogenic bacteria (see Chapter 7). Be aware of federal (and/or National Organic Program) requirements for the interval between manure application and contact with the crop. Current requirements are for 120 days to elapse between the application of manure and harvest.

Irrigation

The irrigation system should be in place and operational before planting for two important reasons: (1) transplants will probably require immediate watering, and (2) any preëmergent herbicide applied after transplanting will need to be watered in by rain or irrigation to be effective. In the early spring of fruiting years, the irrigation system will be a necessary tool for frost protection. Chapter 6 provides details for irrigation design and management.

Preplant Cover Crops

Seeding a cover crop on the site the year before planting is an excellent way to improve soil structure, suppress weeds, and, if the proper cover crop is chosen, suppress nematode populations. Benefits of a cover crop are greatest when the soil is sandy and/or the soil organic matter content is low. Most cover crops grow under the same soil conditions as strawberries; it is unlikely that anything other than nitrogen (40 lbs/acre), and perhaps phosphorus, will need to be added prior to seeding.

Use minimum seeding rates for cover crops when the objective is to supply a harvestable stand of grain or straw. But when a vigorous, dense stand is desired for weed suppression and organic matter, use a higher seeding rate.

Preplant cover crops are usually plowed under in the late fall or early spring before they set seed and prior to planting strawberries. Unless the soil and site are prone to erosion, crops with low nitrogen contents (grains and grasses) should be plowed under early in the fall to allow enough time for decomposition. Legumes contain more nitrogen and decompose quickly, so they can be turned under within a month of planting. Planting directly into an undecomposed incorporated straw residue can slow growth of the strawberry transplants and result in reduced yield the following year.

Some growers are experimenting with planting strawberries into a mowed but unincorporated killed sod of grain rye, rather than planting into bare soil. This method reduces the requirement for herbicides and is discussed more fully in Chapter 4.

In some cases, mixtures of crops are used to realize the benefits of multiple species (e.g., oats and clover together). It is common for growers to plant cover crops sequentially between successive strawberry crops. For example, after the last strawberry harvest, strawberries are plowed under and hairy vetch is sown. It is plowed down in spring and sweet corn is planted. After the corn harvest, rye is planted in fall and incorporated the following spring. This sequence provides supplemental nitrogen, an opportunity for weed management, additional organic matter, and a cash crop. Strawberries are planted again after the rye is incorporated.

Listed below are some common cover crops that perform well in cooler climates; the list is by no means comprehensive.

Alfalfa

Alfalfa is a perennial legume that requires a well-drained soil with a high pH (6.0–7.0). The most desirable periods for planting are early April to late May or late July to mid-August. The recommended seeding rate is 14 lbs/acre. If allowed to overwinter from a spring seeding, alfalfa grows tall enough to become difficult to incorporate. The cost of alfalfa seed is much greater than the cost of clover seed. It is recommended that alfalfa seed be inoculated when seeded on an area for the first time. An advantage with alfalfa is that it provides a substantial amount of organic matter and nitrogen for the subsequent strawberry crop. A disadvantage is that it harbors some of the same diseases and insect pests that affect strawberries.

Buckwheat

Buckwheat can be seeded successfully on sites with low soil pH. While there is fast growth of the top portion of this grain, there is little organic matter contribution from the roots. The plants should not be allowed to mature, since reseeding will readily occur. Early seedings in late May or early June are better than summer seedings in late July. Buckwheat may be seeded at 60 lbs/acre. The rapid growth helps to shade out smaller weeds and its short season allows for multiple crops a year.

Canola/Mustards

Mustards are a popular pre-plant cover crop because they contain certain chemicals (allyl isothiocyanates) that suppress weeds, nematodes, and soilborne pathogens. They also have an extensive root system. Grass suppression is notable with a Brassica cover. Varieties and species with a high glucosinolate content (*Brassica nigra* and B. *juncea*) are preferable over those bred for oil production. Mustards are adapted to cool, wet conditions and are easily established if they are planted in late August and weed pressure is not too severe. Once established, they can outcompete many weeds because of their exceptional cold-hardiness. A seeding rate of 2–4 lbs/acre is recommended. As many as three crops can be planted per season. They should be incorporated before they go to seed.

Clovers: Alsike, Ladino, and White

All of these clovers have low to moderately upright growth and tend to establish a good legume stand in about 10 weeks. Alsike clover, a very short-lived perennial, can be established in low-pH soils. Ladino and other common white clovers respond to high soil fertility (notably phosphorus) and high soil pH. All of these clovers are fair to moderately good nitrogen-producing crops. They establish best when seeded in early April to late May or from late July to mid-August. Early seedings in either season are more successful. A late fall or late winter broadcast application to open ground may be another effective method of seeding these crops, depending on the soil-seed contact that follows.

The cost of seed varies with the type of clover (see Chapter 14). Common white clover and alsike clover are cheaper than ladino. The cost of seed per acre is low for clover preplant cover crops, since the recommended seeding rate is only 4 lbs/acre for alsike and common white clover and 2 lbs/acre for ladino. Volunteer clovers grow naturally in most fields, so it may not be necessary to inoculate clover seed. However, several pounds of seed can be treated with inoculant for only a few dollars.

Clovers also harbor some of the same soil diseases as strawberries, and they take months to establish. But they contribute a significant amount of nitrogen to the subsequent strawberry crop when incorporated into the soil prior to planting.

Clover, Red

Red clover produces a top growth of 12–18 inches and establishes relatively quickly, depending on soil moisture and seed bed conditions. Red clover grows best in a soil pH of 5.6 or higher. Like other clovers, red clover should be seeded in early April to late May or from late July to mid-August. Early seedings in either season are more successful. As with white clovers, a late fall or late winter broadcast application on open, unfrozen soil may produce a successful seeding. Red clover is a good nitrogen-producing crop and is adapted to a broader range of soil conditions than alfalfa. The seeding rate for red clover is 8 lbs/acre.

Clover, Sweet

Sweet clover is a slow- to moderately fast-establishing biennial legume that responds better to higher soil pH than other clovers. It also responds well to soils with good phosphorus levels and is most easily established when seeded from early April to mid-May or during the first half of August. Large, deeply penetrating roots and heavy top growth make large contributions of nitrogen and organic matter to the soil when incorporated. Second-year top growth may exceed 50 inches. This growth must be cut at a lower height before incorporation. The seeding rate is 12 lbs/acre.

Fescues

The fescues are perennial cool-season grasses that are adapted to a wide range of soil types and pHs (although a pH of 6–7 is best). They are susceptible to few diseases and insects. They are used as both a preplant and permanent cover crop in fruit plantings, often in combination with white and red clover, or alfalfa. Plantings are made in fall from mid-August to October, with a seeding rate of 20 lbs/acre for pure stands and 10 lbs/acre for a legume mixture. Kentucky 31, the most popular variety of tall fescue, is quick to establish. When provided with nitrogen, it grows vigorously and outcompetes most weedy species. Sheep fescue and red fescue are 2 less vigorous types of fine-leaf fescues used for permanent covers. A fescue-clover mix is a good choice if it will be 2 years before strawberries are to be planted.

Field Brome, Annual

This fast-establishing winter annual grass has a much more extensive and fibrous root system than most other green manure crops. Seedings made during July and August tend to be much more successful than seedings made in late spring. The following year's spring growth is rapid and, after the seeds ripen in July, the crop will die. If the soil is disked when the seeds start to fall, the crop can be easily reestablished with no further seeding. Since this is not desirable with a preplant cover crop, thoroughly disc or plow down the heavy root system early in the spring. This seed is not readily available, so plans for obtaining it should be made well in advance of the seeding date. Annual field brome is usually seeded at a rate of 20 lbs/acre.

Hairy Vetch

This legume is adapted to a range of soil conditions. It is a moderately fast-growing winter annual when seeded in August or very early September. The best practice to ensure good growth is early establishment. This Hairy vetch can supply much nitrogen to the soil when grown under ideal conditions. In the mid-Atlantic states, hairy vetch can provide up to 125 lbs/acre of nitrogen for the next crop. Hairy vetch is a true vetch with purple flowers and viney growth, and it should not be confused with another legume known as crown vetch, which is commonly seeded along highways for bank establishment. Hairy vetch is seeded at a rate of 40 lbs/acre.

Marigolds
Marigolds suppress weed and nematode populations and are commonly used in Northern Europe. A warm-season crop, marigold germinates only when soil temperatures exceed 65˚F. Plants do not have to flower to provide benefits, and they can be plowed under after growing for just 90 days. Use open-pollinated seed rather than the expensive hybrid seed, and seeds without the flower remnant are easier to handle. Seed at the rate of 5 lbs/acre and shallowly incorporate, then use overhead irrigation to promote germination.

Millet, Japanese
Japanese millet is a fast-growing summer annual that competes well with weeds and establishes faster on cooler soils than sudangrass. If planted between late May and mid-July, millet will grow 4 feet high in 7–8 weeks. Unlike small-seeded legumes and grasses, the large millet seed should be covered with ½–1 inches of soil in a firm seedbed. The planting may be cut back and allowed to regrow at any time after reaching 20 inches of growth. Millet should not be allowed to mature and drop seed. Millet seed is relatively inexpensive; seed at a rate of 20 lbs/acre.

Oats
When used as a very early spring green manure crop, oats should be planted in early to mid-April. Because of fast growth during the spring, plan to incorporate the planting in early to mid-June. Oats will grow on soils with relatively low pH (5.5) and moderately good fertility; however, this crop requires good soil drainage. A mid-August seeding will provide good growth and ground cover for protection against soil erosion during the fall and winter months. Oats will be gradually killed back by successive frosts and will not grow again in the spring. The dead plant residue is easily incorporated with very light tillage equipment. Three bushels of oats (approximately 100 lbs) are seeded per acre.

Radish (Tillage or Forage)
Tillage radish, also known as forage, oilseed, or daikon radish, is a brassica crop that establishes quickly in late summer. It forms large storage roots with a deep taproot that can penetrate compacted soils, and a thick canopy that outcompetes weeds. It winter-kills, leaving a bare soil with nearly no residue for early spring planting. Ideal seeding dates range from late July to mid-August; plants will bolt if seeded earlier. Recommended seeding rates are 4–6 lbs/acre if drilled, and 8–10 lbs/acre if broadcast.

Ryegrass, Annual
Annual ryegrass seedings establish very rapidly in spring or late summer. Ideal dates for spring seedings range from early April to early June; late summer seedings are more successful when made from early August to early September. Heavy root growth and rapid seeding development make annual ryegrass a very desirable green manure cover crop in areas when good soil-water relations can be maintained. Ryegrass will die out early in the second year, leaving a heavy root system and a moderate top growth residue to incorporate into the soil. A seeding rate of 30 lbs/acre is suggested.

Ryegrass, Perennial
Seedings of perennial ryegrass become established more quickly than seedings of other common perennial grasses such as timothy, bromegrass, and orchard grass. The fibrous root system is extensive and, with the vigorous top growth, provides substantial material for incorporation into the soil in early spring. The dry matter root growth of perennial ryegrass is approximately equal to the top growth. For many other crops, the top growth represents 60–70% of the material turned under at plowing. A seeding rate of 25 lbs/acre is recommended. Establishment is best when planted in September. Growers will typically allow perennial ryegrass to grow through the entire next season before incorporating. This seed is more expensive than others, but plantings are perennial so last for several years.

Rye, Winter
Winter rye, a cereal grain, establishes quickly from late summer and early fall seedings, and is known to suppress weeds. However, fall seedings made after October 1 are likely to provide only winter cover and are slower to produce heavy spring growth. Excessive early spring top growth can create tillage problems if the crop is not incorporated by early to mid-May. This date will vary with the location and season. The seed is readily available and is usually

sold in bushel quantities of 56 lbs. Use a seeding rate of 2 bushels/acre to establish. Some growers harvest the straw for mulch so it is one of the most commonly used preplant cover crops for strawberries.

Sudangrass

Sudangrass is a summer annual that requires much heat for good growth. Seedings made in late May or early June will guarantee a more vigorous growth than seedings made in late June or early July. Hybrid sudangrasses may have larger seeds and should be planted at heavy rates. Like millet and sorghum-sudan hybrids, which also have large seeds, sudangrass should be seeded to a depth of ½–1 inches into a firm seedbed. This summer annual will recover after being cut. Because of its tall growth habit, sudangrass should be cut back when growth exceeds 20–25 inches or plowed down if a second growth is not desired. Use a seeding rate of 80 lbs/acre.

Sorghum-Sudangrass Hybrids

This summer annual requires more heat for growth than sudangrass. It is more expensive to establish. This crop will grow to a greater height than sudangrass under ideal conditions of heat, moisture, and fertility; but the 4–6 feet growth is very difficult to incorporate with small or moderately sized tillage equipment. Like sudangrass, this crop will make a second growth if climatic conditions permit. Growth will cease by mid-September if night temperatures drop to near freezing. The seeding rate will vary from 35–50 lbs/acre, depending on seed size.

Preplant Checklist:

Site selection
Good soil texture
Adequate drainage
Availability of quality water
Not too steep or rocky
No herbicide residues
Fits market requirements

Site preparation
Soil test and incorporate amendments
Install drainage if necessary
Implement weed suppression strategies
Increase organic matter
Install irrigation system

Further Reading & Citations

Magdoff, F. and H. Van Es. 2009. *Building Soils for Better Crops*. SARE Handbook #10, USDA, Washington, DC.

United States Department of Agriculture (USDA). *Managing Cover Crops Profitably.* Sustainable Agriculture Publication #3, Washington, DC.

CHAPTER 3

Variety Selection

When selecting which strawberry varieties are appropriate for a particular site, several factors should be considered, including local climate, soil type, crop history, cultural system to be used, and potential markets. Varieties can differ greatly in ripening time, flavor, fruit size, firmness, post-harvest quality, plant vigor, winter hardiness, and disease resistance. A variety that thrives in one site may not perform well at another site. Before making a decision, it is best to consult local variety recommendations from the State Extension Service and look to nearby farmers' experiences with different varieties.

It most situations, several varieties will be grown at a single farm. Using a mix of varieties allows growers to extend the harvest season, address different markets (e.g., pick-your-own (PYO) and shipping), and manage differences in soil type, drainage, accessibility, etc. For example, early-ripening berries tend to bring the highest price at local markets, but they are more susceptible to frost damage and may not provide the highest yields or largest fruit. Mid-season varieties often supply the bulk of the market, but they vary widely in quality, flavor, and growth habit. Late-season varieties can be high quality, but the market for late-season strawberries is often slow, especially in PYO fields. Growing varieties with different ripening patterns will extend the harvest season and thus the sales generated by the crop.

In a 2020 survey of 158 growers in the northeastern U.S. and Canada, the varieties shown in Table 3.1 were considered "tried and true" by at least 20% of respondents (50% for bolded, italicized cultivars).

Table 3-1. Widely grown cultivars in the northeastern U.S. and Canada.

June-bearing	AC Wendy
	AC Valley Sunset
	Cabot
	Cavendish
	Chandler
	Earliglow
	Honeoye
	Jewel
	Annapolis
	Allstar
Day-neutral	***Albion***
	Seascape
	Evie-2
	San Andreas
	Monterey

Short-Day (June-Bearing) Varieties

Table 3-1 lists short-day (i.e., June-bearing) varieties that are commonly grown in colder climates. These varieties can usually be sourced as dormant bare-rooted plants from nursery suppliers in the Northeast, Midwest, and Canada. Plug plants may also be available.

For short-day strawberry varieties without season extension practices grown in zones 3−5, the strawberry season will typically last 3–4 weeks, beginning in early to mid-June through early July. The relative maturity within this season is indicated for specific varieties listed in table 3-2.

Table 3-2. Short-day (June-bearing) strawberry varieties.

Variety	Resistance (R = resistant, PR = partially resistant, S = susceptible)*	Comments (including origin of variety)
Early-Season		
AC Wendy	Red Stele: R Verticillium: PR	Nova Scotia; very early, with good quality fruit and yield. Size diminishes after first harvests. Plants may lack vigor and longevity in far northern sites.
Sable	Red Stele: R Verticillium: R	Nova Scotia; early, with very good quality fruit and yield. Fruit medium size, uniform.
Earliglow	Red Stele: R Verticillium: R	USDA; older variety with excellent flavor. Size diminishes after first harvest, yields low in northern sites, vigorous plants.
Archer	Gray Mold: S Leaf Scorch: S	New York; large early fruit, good quality, long harvest window. May not be adequately hardy for far northern locations.
Annapolis	Red Stele: R Powdery Mildew: S	Nova Scotia; large, early fruit, good quality, may be soft. Short harvest window.
Galletta	Red Stele: PR Leaf Spot: R	North Carolina; large, uniform fruit, good quality. Plants vigorous and productive. Developed for plasticulture but does well in matted row. Short harvest window.
Early Mid-Season		
Honeoye	Red Stele: S Verticillium: S Leaf Spots: R	New York; firm, attractive fruit, long harvest window, with good yields. Flavor often only fair. Vigorous plants in well-drained soils with good bed longevity.
Cavendish	Red Stele: R Verticillium: R	Nova Scotia; good quality and high yields, but may color unevenly. Long harvest window. Vigorous plants, good longevity.
Flavorfest	Red Stele: R	USDA; very high quality fruit with good yield. Vigorous plants. Developed for plasticulture but does well in matted row.
AAC Lila	Red Stele: R	Nova Scotia; large, attractive fruit, very good quality, good yields. Vigorous, disease-resistant plants.
Yambu	Gray mold: R Leather rot: R	Netherlands: large, good quality fruit, long harvest window, vigorous plants.
Brunswick	Red Stele: R Verticillium: R	Nova Scotia; good quality and high yields, dark color, medium size; can be hard to pick. Long harvest window. Vigorous plants, good longevity.
Mid-Season		
Jewel	Red Stele: S Verticillium: S	New York; excellent fruit quality and high yields, with long harvest window. May be sensitive to some herbicides.
Keepsake		USDA; high quality fruit with excellent shelf life and good yield and long harvest window. Developed for plasticulture but may do well in matted row.
Mira	Red Stele: R Verticillium: R	Nova Scotia; good quality, uniform fruit with light color and high yields. Vigorous plants but may have short bed life.
Darselect	Leaf Scorch: S	France; very good quality, uniform, light colored fruit. Long harvest window. Large, vigorous plants, require high soil fertility.

Mid-Late-Season		
Allstar	Red Stele: R Verticillium: R	USDA; high quality, light colored fruit, with good yield. Disease resistance plants, but low runner producer.
Cabot	Gray mold: S	Nova Scotia; very large, rough fruit, good flavor and high yields. Vigorous plants need high fertility and may have short bed life.
Mayflower	Leather rot: R	Great Britain; large, firm fruit, holds well, color may be dull. Good yields.
Dickens	Red Stele: PR	New York; large fruit, good quality and yield with long harvest window.
Sparkle	Red Stele: R	New Jersey; excellent flavor, but fruit are small, dark and soft. Better suited for home than for commercial production.
Late-Season		
AC Valley Sunset	Red Stele: R Verticillium: R	Nova Scotia; large, attractive fruit, good flavor and high yields. Vigorous plants.
Clancy		New York; large fruit, firm, good quality, but moderate yield.
Malwina	Red Stele: R Verticillium: R	Germany; very late, large, dark, firm fruit with good flavor. Vigorous plants.

*Information about varietal susceptibility and resistance is often conflicting, and may change over time as pathogens evolve.

Day-Neutral Varieties

The term "day-neutral" is used by industry to distinguish repeat-fruiting varieties from short-day cultivars. However, the term "day-neutral" may be technically inaccurate for some varieties, such as 'Albion', as Durner (2017) found that long days enhance yield for this variety, suggesting it is a quantitative long-day plant. For this reason, some prefer the more general terms "remontant," "repeat-fruiting," and "everbearing," but these terms are less widely known, may confuse growers, carry other associations, and/or may be used to refer to multiple plant types. For this reason, we use day-neutral in this guide.

Day-neutral varieties can be used to further extend the strawberry fruiting season, both earlier in the spring and through the summer and fall months (see Day-Neutral Strawberry Production in Chapter 4). For day-neutral strawberry varieties without season extension practices (low tunnels, high tunnels, etc.) grown in zones 3–5, when planted as dormant (bare-rooted) crowns, the strawberry season will typically last 12 or more weeks beginning in July and continuing through frost. Day-neutral plantings that are overwintered into a second year tend to fruit earlier in the season than both short-day varieties and day-neutral varieties planted in the spring of that year. Specific timing varies with plant type and age, climate, variety, and season. The relative maturity within this season is indicated for specific varieties in table 3-2.

The selection of day-neutral strawberry varieties has been expanding in recent years and continues to be an objective of several active breeding programs. However, not all varieties are suitable for a cold climate with a short growing season, and growers should carefully consider the research and experience available on the performance of new varieties in colder climates before investing in them. Table 2 lists varieties presently known to perform well. There are other day-neutral varieties not listed in Table 2 that have not been well-investigated in colder regions. For variety pictures, access Growing Day-neutral Strawberries in New Hampshire.

Table 3-3. Day-neutral (fall-bearing) strawberry varieties. See the Day-neutral Strawberry Production Guide for pictures.

Variety	Season	Notable susceptibilities	Comments
Evie 2	Early		Early and productive, medium-size fruit that are very soft and susceptible to rain damage and fruit rot.
Seascape	Early	Powdery Mildew	Early and productive, medium fruit size, good flavor and attractive seedy appearance. Soft fruit that can be susceptible to fruit rot. Marketable yield can drop off by mid-season as fruit size declines, but some report improvements in fruit size later in the season. Low runnering tendency by comparison to some varieties.
Portola	Mid	Leaf Spot, Fruit Anthracnose	Large, light colored fruit that are soft with tender skin. Eating quality may be mediocre and fruit size can be very small depending on the health of the planting and plant stock.
Sweet Ann*	Mid		Large fruit with good flavor. Fruit are light-red in color and soft with tender skin. High runnering tendency but runners are often tender and easy to remove. Marketable yields have been greater under protected culture than traditional open beds.
Albion	Mid-late	Anthracnose	Medium to large fruit that are uniform, juicy, and firm. Very good flavor when fully ripe. Plants can be vigorous if plant fertility is adequate. Produces moderate runners.
San Andreas	Mid-late		Large, attractive, juicy, and firm fruit with good flavor. Produces moderate runners. Take care to harvest when fully ripe for best eating quality.

*Data based on a limited number of evaluations in the Northeast region.

Further Reading & Citations

Handley, D.T. Strawberry Varieties for Maine. The University of Maine Bulletin #2184.

Orde, K. and B. Sideman. 2019. Growing Day-neutral Strawberries in New Hampshire: Variety Selection and Production Tips. University of New Hampshire Cooperative Extension Publication.

Nursery Guide for Berry and Small Fruit Crops. Cornell University.

CHAPTER 4

Production Systems

Strawberry plants are adaptable to a variety of growing methods. The matted row system is the most common method in the Northeast and Midwest. It is a perennial system, which produces good yields of fruit in the early summer, with low initial costs and only moderate risk. Other perennial systems, such as ribbon rows, are more expensive to establish and maintain but may produce significantly higher yields and better fruit quality than the matted row. Annual plasticulture systems, popular in the southeastern and western U.S., can produce very high yields and earlier maturing fruit. However, the initial inputs for these systems are much higher, and the risk of failure increases as one moves north into shorter growing seasons and colder winters. Day-neutral strawberries can extend the strawberry harvest season from 5 weeks to 4 months but growing and marketing the off-season crop is more capital and labor-intensive compared to June-bearing strawberries. Greenhouses and other protected environments offer growers the opportunity to produce high-quality strawberries in midwinter (figure 4-1) but require significant investments in technology, labor and operating capital.

The system(s) one chooses will depend on the targeted time of year to produce and market strawberries, the types and the markets in the area, and one's aversion to risk. Several options are presented in this chapter with their advantages and disadvantages.

The Matted Row System

The **matted row** is the most popular system in northern areas of the United States and Canada because of its relatively low establishment costs, low labor requirements, and long history of success in colder climates. It exploits the natural growth habit and pattern of June-bearing strawberry plants. Dormant strawberry crowns are initially planted at a wide spacing in the spring, and during the summer runners that emerge from these plants are allowed to root and fill in the space between them. The first harvest occurs the year after planting, usually in June, and yields of 7,000–15,000 lbs/acre can be expected. The beds are renovated after harvest and are typically carried over for 3–5 harvest seasons in conventional systems; they are typically harvested for only 1–2 seasons in organic systems.

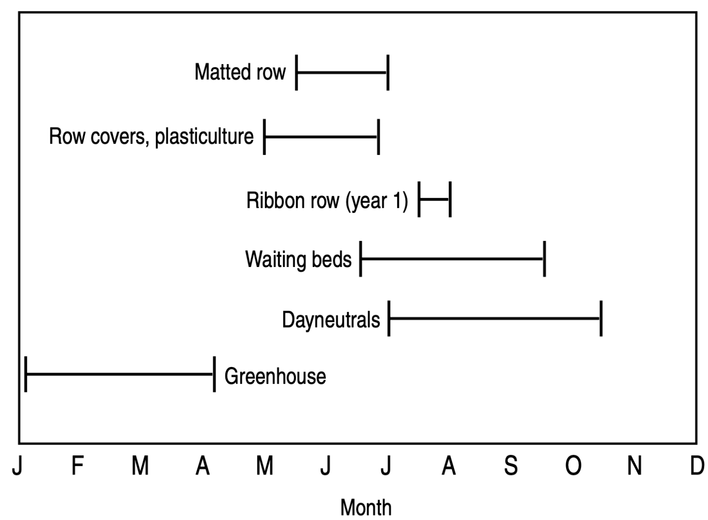


Figure 4-1. Expected harvest season for strawberries grown under various production systems.

Planting

The planting year schedule for the matted row system is summarized in table 4-1. Site preparation should begin the year before planting to bring the soil pH and nutrients to optimal levels for strawberry plants (see Chapter 2). To ensure adequate supplies of desired varieties, order dormant crowns from a reliable nursery in the late fall or early winter for planting in the spring. Specify a shipping date that will match the expected planting date. It is generally best to set the plants early in the spring; as soon as the soil can be worked, typically April or May. Planting later than July 1 will usually result in poorly filled beds. Because dormant plants lose vigor after too much time in storage, the new roots will grow poorly in hot, dry soils, the plants will not have enough time to produce adequate numbers of runners, and the runner plants will not produce enough leaves to promote good flower bud initiation. However, if late planting is required, it is best to increase the number of crowns planted per acre by reducing the in row spacing (e.g., from 18–12 inches apart) to compensate for fewer viable runners that result from this practice. Some growers intentionally plant late at a higher density to avoid weed pressure in May and June.

Table 4-1. Planting year summary schedule.

Activity	Approximate Timing
Plant dormant crowns	April or May
Weed control	May
Remove flowers	June or July
Fertilize	June
Position runners	July through September
Weed control	August
Fertilize	September
Weed control	November
Mulch	late–November

If planting on raised beds, the top of the beds should be 16–20 inches wide and 4–6 feet apart, on center. Before planting, soak dormant transplants (photo 4-1) in water for an hour or so. Set the dormant crowns 18–24 inches apart within rows, and 4–6 inches apart between rows (5,000–8,300 plants/acre) (figure 4-2, table 4-2, photo 4-2 and photo 4-3). Narrower row spacing requires higher numbers of plants and, though generally more productive, will cost more to establish and result in narrow walkways between the rows, which makes picking more difficult and increases damage to the fruit during harvest and spraying. Crowns should be set such that the roots are fully extended in the planting hole, and the soil comes to halfway up the crown. Planting too shallowly will cause the plants to dry out and be poorly anchored. Planting too deeply will result in the growing point at the tip of the crown to be buried, which can slow or stop its development.

Irrigate the plants after planting, and water them regularly to encourage plant establishment and ensure optimum growth; 1–2 inches of water per week is usually adequate for most soil types (see Chapter 6).

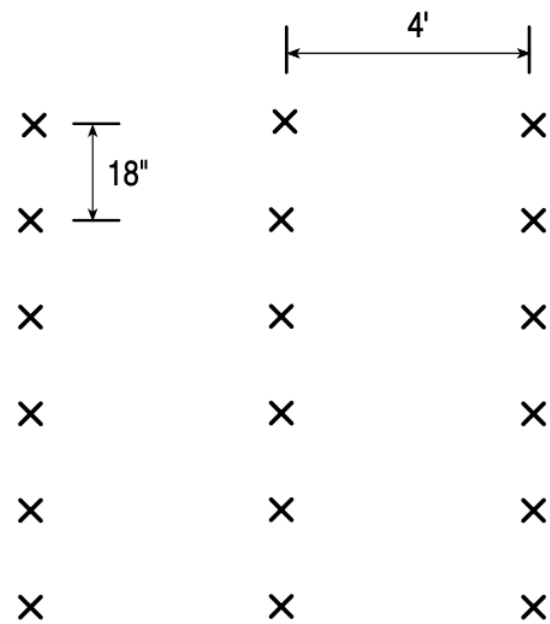


Figure 4-2. Spacing diagram for the matted row system.

Table 4-2. Required plant numbers per acre for a given spacing between and within rows.

PLANTS/ACRE							
SINGLE ROWS							
Within row spacing (inches)	**Between row spacing (center-to-center) (feet)**						
	3	**3.5**	**4**	**4.5**	**5**	**5.5**	**6**
3	0	0	43,560	38,720	34,848	31,680	29,040
6	0	0	21,780	19,360	17,424	15,840	14,520
12	0	0	10,890	9,680	8,712	7,920	7,260
18	0	0	7,260	6,453	5,808	5,280	4,840
24	0	0	5,445	4,840	4,356	3,960	3,630
DOUBLE ROWS							
Within row spacing (inches)	**Between row spacing (center-to-center) (feet)**						
	4	**4.5**	**5**	**5.5**	**6**	**6.5**	**7**
3	87,120	77,440	69,696	63,360	58,080	53,600	49,760
6	43,560	38,720	34,848	31,680	29,040	26,800	24,880
12	21,780	19,360	17,424	15,840	14,520	13,400	12,440
14	18,669	16,594	14,935	13,577	12,446	11,486	10,663
16	16,335	14,520	13,068	11,880	10,890	10,050	9,330
18	14,520	12,907	11,616	10,560	9,680	8,933	8,293
24	10,890	9,680	8,712	7,920	7,260	6,700	6,220

Flower Removal

In the weeks after planting, leaves and flowers will emerge from the crowns. Flower trusses should be removed from the crown as they appear during the planting year. This practice will encourage more vigorous vegetative growth and improve plant establishment, leading to better harvests the following year. The trusses can be easily pinched off when they are still in the bud stage, but scissors or clippers may be needed if fruit has started to develop, as the stems become woodier with time (photo 4-4). Going through the field 3–4 times over a period of 2–3 weeks when flower trusses first appear should be adequate to get most of them removed.

Flower buds in June-bearing strawberry varieties are formed in the in the fall in response to shortened day lengths. Dormant plants received from a nursery are dug in the fall, after flower buds have been initiated. Flower removal will reduce stress on the transplanted crowns. The amount of fruit produced from first-year flowers would be of little value due to the low plant density. Allowing fruit to develop and then not harvesting it would encourage disease problems.

Photo 4-1. Dormant strawberry crowns commonly used for spring planting (K. Orde).

Photo 4-2. Newly planted dormant crowns (D. Handley).

Photo 4-3. Newly planted dormant crowns (D. Handley).

Photo 4-4. Removing flowers from new plants to encourage establishment (K. Orde).

Photo 4-5. Runners produced under long days of summer (D. Handley).

Photo 4-6. Cultivating between rows during the first year (D. Handley).

Runner Plant Establishment

Runner or daughter plants will emerge from the crowns in the early summer (photo 4-5). These should be allowed to root between and on either side of the initially planted crowns, or mother plants, to fill out the rows and establish the desired plant density for optimal yields next year. The plant rows should not be allowed to exceed 18 inches in width. Runner plants falling outside this width should be moved back into the row or cut off. If plant rows are allowed to get too wide, plants in the middle of the row become shaded, and competition for nutrients and water will stress and weaken them. The earlier the runner plants root and become independent of the mother plants, the more flowers and fruit they will produce next year. Late formed runners tend to be small and may not have time to form an adequate root system to survive the winter. These can be removed if they are extending out beyond the recommended 18 inch row width with a cultivator set up with disks at the appropriate width to cut off runner plants in the aisles (photo 4-6). Runner plants are stimulated to form roots by soil moisture. Encourage root development by regular irrigation during the summer months when runners are forming (photo 4-7). By late summer, the beds should be well-filled, and have an average of 4–6 plants/foot of row.

To maintain sufficient fertility the first growing season, nitrogen fertilizer should be applied at a rate of 30 lbs/acre 4–6 weeks after planting, and a second application at the same rate should be made in mid- to late August to ensure adequate fall growth.

Controlling weeds can be challenging in the matted row system because there is a lot of bare soil surface until the runners become well established. Following planting, one or more preëmergent herbicides can be applied after the soil has settled around the roots of the plants. Frequent, shallow cultivation is also an important part of early weed management, as well as hand-weeding within the rows. Unmanaged weeds can take over a strawberry bed, causing reduced yield and fruit quality. Good weed management can greatly increase the productive life of the planting.

Mulching

Strawberry plants will go dormant for the winter months but need to be protected from extreme cold and desiccation to prevent injury or death, which results in poor yield in the spring. Mulch is applied in the late fall, after the plants have gone "dormant," usually between mid-November and early December. Strawberry plants don't enter true dormancy and drop their leaves like most woody perennial plants, rather they slow their growth and build up starch in their roots, crowns, and remaining leaves as they prepare for winter. Dormancy is typically determined by the leaves turning red or orange and wilting down around the crowns (photo 4-8). Mulch should not be applied over plants that are not yet dormant. This will stress the actively growing plants that are forming flower buds and reduce yield and fruit quality next spring. As soon as the temperatures warm in spring, strawberry plants can grow after experiencing just 200 hours of chilling.

An application of 3–6 inches of straw over the plants provides protection from both cold temperatures that could damage crown tissues and warm temperatures that could prematurely stimulate growth. One ton of straw provides about 1 inch of cover per acre (photo 4-9). Most fields require 3–5 tons of straw per acre to get adequate coverage. See Chapter 5 for a detailed description of mulching options and temperature control during this critical period of development.

The mulch should be raked off the top of the beds in the early spring (March or early April) and left in the aisles between the beds to reduce weed germination and to provide a dry medium on which the fruit can develop to reduce potential disease problems (photo 4-10). Leaving the mulch on too long into the spring will stress the plants and result in later ripening and lower yields. Following mulch removal, light applications of nitrogen (approximately 20 lbs/acre) and boron (approximately 2 lbs/acre) are typically applied to stimulate new growth and promote healthy flower and fruit development (see Chapter 7).

Photo 4-7. Drip (trickle) irrigation efficiently uses water (D. Handley).

Photo 4-8. Red leaves are an indication of dormancy (D. Handley).

Photo 4-9. Plants mulched with straw for winter (D. Handley).

Photo 4-10. Straw mulch is raked into the alleyways after winter (K. Orde).

Photo 4-11. The darkened center of the blossom is evidence of frost injury (D. Handley).

Photo 4-12. Irrigation pipe and risers for providing overhead irrigation for frost protection (D. Handley).

First Harvest

Buds and flowers emerging from the crowns early in the spring are susceptible to frost damage. When unprotected buds are injured by frost, the normally yellow center of the blossom will be blackened (photo 4-11). Such flowers will not produce fruit. Buds and flowers can be protected with overhead irrigation (photo 4-12) run continuously during periods of below-freezing temperatures (see Chapter 5 for details on frost protection). Fabric rowcovers can also be used alone or in combination with irrigation for frost protection.

Bloom is also a critical time for pest managment. Tarnished plant bug, strawberry bud weevil, two-spotted spider mites, and gray mold infections are all significant threats during bloom, and should be monitored and managed accordingly (see Chapters 8 and 9).

The first fruit is usually ready for harvest about 3–4 weeks after full bloom. The harvest season may last from 3–5 weeks, or longer, depending on the number and selection of varieties and the weather.

Bed Renovation

Renovating a strawberry bed is basically a thinning process to promote healthy new growth that can support a good crop next spring. Renovation should begin as soon after harvest as possible, usually mid-July to early August. The earlier the beds get renovated, the more time new runner plants have to develop, leading to larger crowns and more flower buds for next year. Early renovation also improves weed management by tilling in many weeds before they go to seed, and can reduce insect, mite and foliar disease problems by interfering with their life cycles at a critical stage of development. Renovation should be carried out every year after harvest for the life of the bed. Matted row strawberry beds typically produce well for 3–5 years, but this varies depending on variety, site and management.

The first step in the bed renovation process is to determine which beds should be carried over for another year and which should be plowed down and put into a crop rotation. Beds that did not suffer much from winter injury had good production and a good plant stand with no major weed, insect or disease problems should be carried over for another year. Beds that do not meet these criteria should be plowed down and seeded to a suitable cover crop to reduce weed, insect and disease problems that have developed, and to increase soil organic matter content. Ideally, beds that are plowed down should be rotated out of strawberries for at least 3 years. If properly managed, crop rotation will greatly reduce pest problems and improve the vigor and longevity of strawberry beds without the need for soil fumigation.

Directly following the last harvest, assess and manage weed problems that have developed in the bed. If perennial broadleaf weeds such as dandelion, shepherd's purse, daisy or goldenrod, or annual broadleaf weeds such as lambsquarters, sorrel or pigweed are present, hand-pull as many as possible within the plant rows, and/or apply a postemergent broadleaf herbicide (2,4-D amine, clopyralid). Four to five days following the postemergent herbicide application (or immediately if an herbicide was not applied), mow the leaves off of the strawberry plants 2–3 inches above the crowns (photo 4-13). This is typically done with a bush hog or flail mower. A new flush of leaves will follow soon and removing the old leaves can reduce foliar diseases, insects and mites. If the planting is weak or drought stressed, do not mow the leaves, as it may add to the stress the plants are experiencing.

Following the mowing, apply 40–60 lbs/acre of actual nitrogen (use the higher rate on sandy soils and fields where growth has been weak). Phosphorus and potassium applications may be necessary depending on soil test and/or leaf analysis recommendations.

The next step is to narrow the rows back to a width of 12–18 inches by tilling in the sides of the row and leaving a strip in the center (photo 4-14 and 4-15). Use the wider setting for varieties that tend to throw few runners or any fields experiencing drought stress. This is usually accomplished with a rototiller which has had some of the center tines removed, or a multi-headed tiller set to the desired width. Set the tiller depth and speed so that it incorporates the excess crowns, mowed leaves and fertilizer into the soil, while at the same time spreading about 1 inch of soil over the remaining crowns.

Photo 4-13. Leaves are removed after harvest as part of the renovation process (M. Pritts).

Photo 4-14. Rows are narrowed as part of the renovation process (D. Handley).

Photo 4-15. Strawberry field after renovation in late July (D. Handley).

Photo 4-16. Plasticulture production on black plastic mulch (K. Orde).

Photo 4-17. Plasticulture production on white plastic mulch covered by low tunnels (K. Orde).

Photo 4-18. Dormant (bare-rooted) crowns come shipped in a box in bundles (D. Handley).

This will reduce leaf disease and mite problems, and help stimulate new root growth on the remaining plants.

If soil compaction is a concern, use a subsoiling blade between the rows to break up compacted layers of soil. This will improve water infiltration and soil aeration. Compaction can be caused by tractor and picker traffic in the field, and can create soil drainage problems and interfere with good root development. Subsoiling is best done late in the renovation sequence to prevent interference from straw and crop residues.

Renovation is an optimal time to apply preëmergent herbicides to prevent the germination of many annual weed species that can become problematic during the summer and fall (e.g., terbacil, napropamide, DCPA, pendamethalin). These are most effective when applied just after tilling and irrigated into the soil. Be sure to follow all product label instructions and precautions when using these products. If herbicides are not used, regular light cultivation and hand weeding, before weeds are more than 2 inches tall, will be needed throughout the summer (see Chapter 10).

To encourage rapid plant growth and optimize applications of fertilizers and herbicides, irrigate immediately following the renovation process and regularly throughout the remainder of the season. Strawberries will grow best if they receive 1½ of water per week during the growing season.

Nutrition

Following the application of 40–60 lbs/acre of actual nitrogen at renovation, another 20 lbs/acre of nitrogen should be applied in mid- to late August to stimulate flower bud development. One way to determine the nutrient status of strawberry plants during the summer is to have a leaf tissue analysis done. Tissue analysis offers a view of what is happening within the plant and can spot any nutrient deficiencies. In combination with regular soil tests, tissue analysis will provide a complete picture of a field's fertilizer needs (see Chapter 7).

Organic Production

Demand for organically grown strawberries is very high, and may offer significant price advantages in the market. However, the cost of production is also higher, due to several factors, including shorter production cycles (1–2 harvest years vs. 3–5 for conventional) with longer crop rotations, 20-30% lower yields, reduced fruit quality, and higher labor demands. These factors incur significantly higher costs for organic production versus conventional practices, but if the price differential approaches 35–40%, the organically grown berries may bring profits equal to or higher than conventionally grow fruit. Organic production costs can be estimated using the budgeting resources in Chapter 14.

Short crop rotations are key to successful organic production. Organically grown fields should only be fruited for 1 or 2 years, in order to minimize the buildup of weed and pest populations and to maintain sufficiently high levels of available nitrogen in the soil. For example, following 3 years of appropriate cover crops (e.g., rye, corn, buckwheat, sudangrass) and manure applications (if needed), a field of strawberries could be established 1 year, fruited the next year, and then the bed would be plowed down and returned to cover crops and/or suitable annual cash crops for the next 3 years. If weed populations are not significant during the harvest year, and can be easily managed with cultivation and hand weeding, a second year of cropping may be worthwhile, but expect weed issues to become much more prominent in the second harvest season, and therefore more difficult to bring back under control.

Weeds tend to be the most significant problem for organic matted row production. The short rotation cycle recommended will not only reduce weed problems, but can also reduce both insect and disease issues as well by eliminating overwintering sites for pests and preventing the buildup of pests by reducing the availability of the host plants. In addition to the short rotation cycle, regular cultivation and mulching can help reduce weed problems. Planting in narrow rows, selecting varieties with disease resistance, and managing the surrounding vegetation to reduce pest habitat, are also important pest management strategies for organic production.

The Ribbon Row System

The **ribbon row system**, like the matted row, is a perennial system that will be harvested for several seasons and renovated, or thinned, after harvest. However, in the ribbon row, dormant crowns are initially planted at very high densities in the spring then harvested in the summer of that same year, prior to the formation of runner plants. This provides some early cash flow and may offset the higher initial cost of plants. Second year yields may also be higher than a typical matted row, because of the high proportion of two-year-old plants to rooted runners in ribbon rows. The older plants have more and larger branch crowns and yield higher on a per plant basis than the runner or daughter plants. Because the initial planting density is very high few, if any, runner plants are used in the ribbon row system, because allowing them to establish would result in over-competition within the beds. Therefore most, if not all, runners are removed as they appear. This is a labor intensive and costly chore. Furthermore, planting costs are significantly higher (an additional $3,000 or more per acre) than the matted row system. There remains some debate as to whether the additional harvest and higher yields of this system truly offset the increased expense and labor it requires.

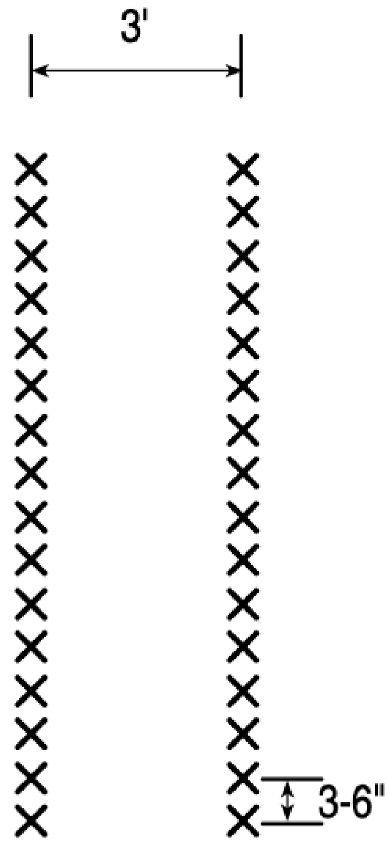


Figure 4-3. Spacing diagram for the ribbon row system.

Planting

Pre-plant preparation for the ribbon row system is essentially the same as matted row culture. Row spacing is often closer, however, with the plants set on narrow raised beds (12–18 inches wide on top) 3–4 feet apart on center. Plants should be spaced just 4–8 inches apart in a single row on top of the beds (29,000-58,000 plants/acre) (figure 4-3). Water the plants in well to encourage good early growth and root development. Mulch the alley between rows with straw to inhibit weed growth and provide a dry surface for fruit development and harvest.

First-year Harvest

Flowers are usually not removed in the ribbon row to obtain a small crop in the planting year. Harvest will usually begin about 8 weeks after planting.

Renovation

Following the second year's harvest, the beds should be renovated using steps similar to the matted row; mow off the leaves, apply fertilizers and any herbicides needed, and re-shape the beds with a rototiller or harrow. Since raised beds used in the ribbon row require more straw for winter protection, more straw may be present in the alleyways than can be worked into the soil. Some growers remove this mulch before renovation. Following renovation, runners will emerge from the plants. Few, if any of these runners are needed, because the desired plant density is already set, so they should be removed. However, in the second year the number of runners formed will be much higher than in the planting year, and it may be too costly or impractical to remove them all. Therefore, some growers allow the beds to form matted rows in the second year, widening the top of the bed, and allowing some of the runners to root. If the bed is carried over for a fourth year, it is treated and renovated as a matted row. Fertilization practices are the same as a standard matted row.

Runner Removal

After harvest, most runners should be removed at regular intervals by pinching or clipping them before they root. Some runners may be allowed to develop and root where there are gaps in the bed between the initially planted crowns. Allowing the plants to fruit in the first year may help suppress runner development.

Mulching

Winter protection for the ribbon row is the same as for matted row beds; heavily mulch the beds after the plants have gone dormant in the late fall to early winter. Uncover the plants by raking the mulch into the aisles between the beds in the early spring.

Second Harvest

Flowering and fruiting will occur at the normal time in the second year but yields in the ribbon row can be significantly higher than with matted rows, and may exceed 20,000 lbs/acre. Fruit size may also be larger than the matted row system.

Annual Plasticulture

Although the matted row has been a successful and profitable production system for many years in the colder regions of the country, plasticulture systems, widely adopted in other climatic regions (e.g., California, Florida) may, with significant modifications, be adapted to more northern growing conditions. Advantages of plasticulture can include earlier harvest, higher yields, improved fruit quality, better harvest efficiency, and better weed control. Disadvantages may include higher initial costs (plastic, plants, labor), increased winter injury, more frequent re-planting, difficulty in obtaining planting stock, increased disease pressure, and higher risk of spring frost injury. While plasticulture systems tend to offer significantly higher yields in their first harvest over matted row production in northern regions, the costs are significantly greater and thus profitability is often comparable. However, for growers who are accustomed to using plastic mulches in vegetable systems, or who are interested in alternatives to the matted row for extending the harvest season, plasticulture may be a viable option. It is important to note, however, that plasticulture has been most successful where it is used as a winter production system in warm climates where moderate temperatures and shorter day lengths allow for continued growth, flower initiation is prolonged, and runner growth is greatly reduced. Regular soil fumigation is usually an integral part of controlling weeds and soil borne pathogens in these systems.

Synopsis

For **annual plasticulture**, plants are set at a very high density on raised beds covered with black or white plastic mulch and supplied with drip irrigation (photo 4-16 and 4-17). Planting occurs during the summer when the day lengths are beginning to shorten (late August and September), so that little runnering will occur and flower buds will begin to form. The plants produce 1–3 large crowns before going dormant in the fall. The beds are typically protected during the winter with rowcovers and irrigated for frost protection in the spring. Straw is sometimes used for overwintering but a thick layer is needed on the edges of beds to prevent it from being blown off the plastic mulch during wind. The plants will flower and fruit much earlier than matted rows because of the plastic mulch and rowcovers. Following harvest of June-bearing varieties, the beds are taken out and planted to cover crops or a short season cash crop, e.g., cucumber, lettuce, broccoli. New beds are then planted for the following year. Beds are not typically carried over a second year because labor costs of controlling runners are too high, older plants tend to produce smaller, lower quality fruit, and pest issues become difficult and costly to manage.

Varieties

See Chapter 3 for a complete variety list. The California variety Chandler has been the most successful for plasticulture in the northern regions, but most strawberry varieties that perform well in the matted row system will probably do the same in a plasticulture system. Some of the June-bearing varieties that have worked well include Galletta, Jewel, Flavorfest, Darselect and Valley Sunset. For day-neutral varieties, the best selections include Seascape, Albion and San Andreas. Most varieties bred for plasticulture in Florida and California do not have adequate hardiness to perform well in colder climates.

Soil Fumigation

It is important to note that the success of plasticulture systems in California, Florida and other southern locations has been dependent on annual soil fumigation prior to planting. Fumigation is the primary strategy for controlling weeds, soil borne diseases and soil inhabiting insects. Without fumigation, fields have shown significant reductions in yield and fruit quality. As soil fumigation chemicals face increased scrutiny and regulation for their environment impacts, alternatives to fumigation are being sought, but none have yet proven as effective for pest management and promoting high production. Soil fumigation is not common for strawberry production in the northern regions; it usually must be custom applied, there is a short application window, and it is quite costly. However, it can provide excellent weed and soil borne pest control, and may be considered among other options, such as long-term rotations and pest-inhibiting cover crops, including winter rye and mustards.

Bed Preparation

Fertilizer should be applied and worked into the soil prior to planting, including 60–100 lbs of slow-release nitrogen. Phosphorus and potassium rates should be determined through soil tests taken the previous fall.

Plasticulture beds should be raised 6–10 inches high, and 24–42 inches wide, spaced 60–72 inches apart on center. They should be no more than 300 feet-long (photo 4-16). Exact dimensions will depend on the type of equipment available, and the number of plant rows desired on each bed. Having the bed smooth and firm before laying the plastic is critical to getting good mulch to soil contact. Working the soil with a rototiller just before shaping it with a press pan is often helpful. Having the center of the bed "crowned", i.e., higher than the edges, will help to shed water, reducing the incidence of diseases. Most plasticulture beds have 2 rows of plants, although some have a single row or as many as 4. For each row of plants, a line of drip irrigation tape should be laid as the beds are being formed, 3–4 inches below the surface and just inside of the plant row. Lay the plastic mulch snugly over the raised beds, with the sides secure, and the ends tucked under soil. Feed the ends of the drip tape through slits in the plastic at each end of the row. Black plastic generally provides the best results in New England; other growers may use white or white on black plastic, or even a combination of both. Clear plastic allows too much weed growth on the beds. White plastic, although it keeps the plants cooler during the summer months, tends to result in lower yields when spring and fall are cool. Black plastic mulch can be over-sprayed either before or just after planting with dilute white latex paint (1:8). The paint temporarily cools the surface of the mulch to prevent heat stress in the new plants, but wears off in time to allow the warming benefits of black plastic in the fall.

The aisle ways between the beds may be left bare and kept free from weeds with herbicides, or mulched with straw, seeded to a weak grass such as annual rye, or covered with landscape fabric.

Do not spray preëmergent herbicides over the plastic mulch on the beds; the chemicals can run off and concentrate in the planting holes.

Plant Types

Three types of plants can be used for the annual system: dormant crowns, plug plants, or fresh-dug plants.

Dormant crowns are the most common type of plant used for plasticulture in the North. These are the same type of plants used in the matted row and ribbon row systems, i.e., plants rooted in nursery beds the previous year, harvested when dormant in the fall, stored through the winter stored through the winter and planted in the spring or summer (photo 4-18).

Plug plants are runner plants (tips) that are removed from mother plants during the summer and rooted in plug trays under mist beds, usually for late-summer or fall planting (photo 4-19). These plants are not generally unavailable until late summer or early fall, as they must have adequate time to root before they can be established successfully. Plug plants are more expensive than the other types because of the increased labor to produce them and shipping costs, but are popular in more southern locations such as North Carolina and New Jersey where long autumns allow for good establishment prior to winter.

Growing Plug Plants

Plug plants are an alternative to dormant bare-root plants that are usually acquired from plant nurseries. Depending on the location of the nursery, they may offer a different selection of varieties than are commonly planted as dormant bare-rooted plants. This will likely change over time as plugs become more popular in colder regions. If you're unfamiliar with the varieties being offered, ask the nursery which varieties they would recommend for your location and consider trying several varieties and a limited quantity to ensure the system is successful at your location. It may take time to identify the best late-summer or fall planting date to ensure adequate fall crown development.

It is also possible to propagate plugs on-farm, as older strawberry varieties that are no longer under patent protection may be propagated. However, do not propagate from plants that are still under patent protection as these are federally protected by the Plant Variety Protection Act that grants plant breeders intellectual property rights over the varieties they develop for a period of time. Protected varieties can only be propagated (for fruit production or plant sale) by a licensed propagator. Nurseries usually indicate on their website or on a tag in the packaging if a variety is still protected; if it is unclear, contact the nursery directly and do your research on the matter. For permission to propagate protected varieties, contact the patent holder to discuss propagation options and plant sources for propagation. It is likely that propagation agreements will require the collection and payment of royalty fees to the patent holder for all plants produced and sold.

The process of creating a plug plant with a runner tip is relatively easy, but it can be difficult to obtain enough runner tips at the right time if quantity is needed. It can also be difficult to manage the transfer of disease. If anthracnose, botrytis, or other pathogens are present in a plant that is to be propagated, these pathogens can be unintentionally transferred into a new planting via the daughter plant; thus, preventative disease management is paramount in plugging operations. Plug plants and runner tips that are purchased directly from nurseries may be more likely to be disease free because many nurseries use fumigation and take preventative measures to reduce disease, but resistance to chemical control and weather conditions can make full control difficult. Nurseries do, however, propagate from plants that are relatively close in generation to the "mother plant", which should be grown using meristem tip culture and verified virus and disease free.

To create plug plants, collect runner tips from healthy strawberry plants in the field in July, or grow plants in raised troughs in a greenhouse or high tunnel and cut them as they hang down (photo 4-20). A warm environment (75-85˚F) induces earlier runnering and a greater number of runners, and raised troughs reduce the need to bend over as much. Tips should have 1 or 2 leaves with roots less than ⅜ inch long (photo 4-21 and 4-22). Tips may be stored in plastic bags and refrigerated (close to 32˚F is preferred) until enough have been collected to fill the desired number of trays. Stick the tips into plug trays (50 count) filled with growing media (e.g., ProMix, photo 4-23) or use starter plugs (e.g., Rockwool, photo 4-24). Tips may be held down with a small U-shaped staple to ensure root-soil contact or pushing slightly into the wet potting soil, but this is not necessary. Place trays in a shaded greenhouse or outdoors on landscape fabric with overhead shading. Placing plants under mist (photo 4-25 and 4-26) or sprinklers that are on a timer is likely to improve the success rate over periodic hand watering (photo 4-27). Keep tips moist for about 7-14 days until rooting occurs (photo 4-28). The original peg roots will produce white lateral roots when they have established.

For the next 2 weeks, water the plants regularly, then move them into full sun. Be sure to continue watering regularly since the root volume is quite small and plants can dry out quickly. Once the entire plug can be lifted out of the tray without the soil falling off the roots (about 5 weeks), they are ready to plant in the field (photo 4-29 and 4-30). Irrigate them frequently for a few days after transplanting to ensure their survival.

Be aware that taking tips from the field in July may not allow enough time for them to be ready for planting in late-August. Starting dormant crowns in a warm greenhouse in April or May will promote runnering earlier, and allow for planting in August. In this case, remove flowers from the mother plants so they produce more runners.

Photo 4-19. Healthy plug plant grown in a 50-cell tray (D. Handley).

Photo 4-20. Runners hanging (J. Allred).

Photo 4-21. Tip with short roots (J. Allred).

Photo 4-22. A group of runner tips (J. Allred).

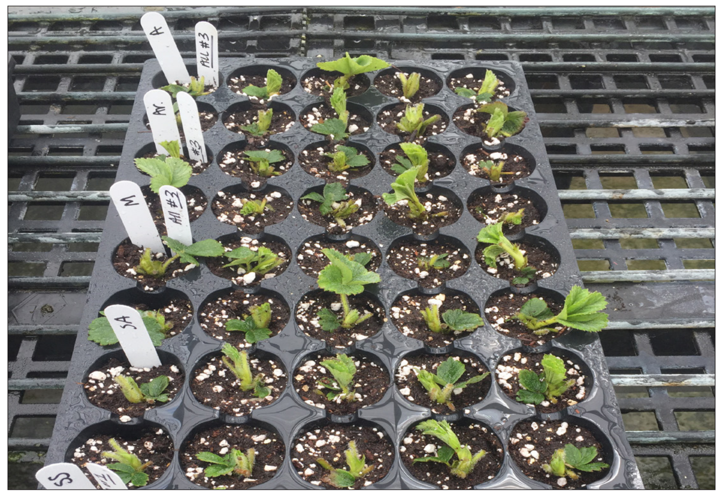


Photo 4-23. Runner tips in a 50-cell tray with potting mix (K. Orde)

Photo 4-24. Runner tip in a rockwool (J. Allred).

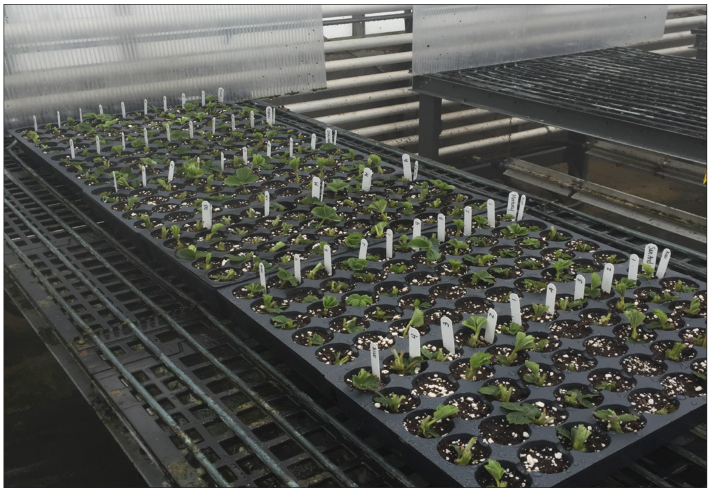


Photo 4-25. Newly plugged runner tips under mist in a greenhouse (K. Orde).

Photo 4-26. Established runner tips under mist (J. Allred).

Photo 4-27. Runner health after being rooted under mist (left) and in a greenhouse with periodic overhead watering (right) (K. Orde).

Photo 4-28. Root systems that developed on tips (J. Allred).

Photo 4-29. Plug plant ready for planting (J. Allred).

Photo 4-30. Well-developed root system ready for transplant (J. Allred).

If plugs are desired early in the season, dormant crowns can be planted into deep greenhouse plug trays (approximately 2 x 2 inches) and left to grow for a few months, then planted into the field at high densities. Runners are easier to remove when plants are initially grown in a greenhouse on benches. Day-neutral bare-root plants may be started in plug trays in February, then planted into the plastic beds in May, giving them a head start on the season.

Fresh-dug plants are also rooted in nursery beds the season before planting, but are not dug until just before planting. For day-neutral varieties, they may be dug in the spring. For short-day varieties, the availability is highly dependent on nursery. Because these plants may have already started growing, they may be more difficult to plant, and are more sensitive to growing conditions, primarily drought. They require prolonged and significant amounts of water for establishment immediately following planting.

Planting

The most common plant spacing for this type of plasticulture is 2 rows of plants atop each bed, with 12–24 inches between rows, depending on the bed width (photo 4-31). Plants within rows are spaced 9–14 inches apart, based on type of plant used and planting date (e.g., later planting = closer spacing, and smaller plants = closer spacing). Plants are usually set in a staggered pattern in the rows, such that a plant in one row aligns with a space between plants in the adjacent row (figure 4-4). This design will require 15,000-17,500 plants/acre. If narrow beds are used (12–18 inches wide), then a single row should be used; on wider beds (36-42 inches wide) 3–4 rows can planted on each bed, but in this situation the inner rows tend to produce less than the outer rows, harvest is more difficult, and diseases tend to be more prevalent.

It is helpful to mark the plant spacing on the plastic mulch prior to planting. This can be done with a measuring tape, marking plant spacing by dimpling the plastic with a finger. For large plantings, a marking wheel can be made from a bicycle wheel rim with small cleats screwed on to it, placed to mark the plastic at the desired spacing.

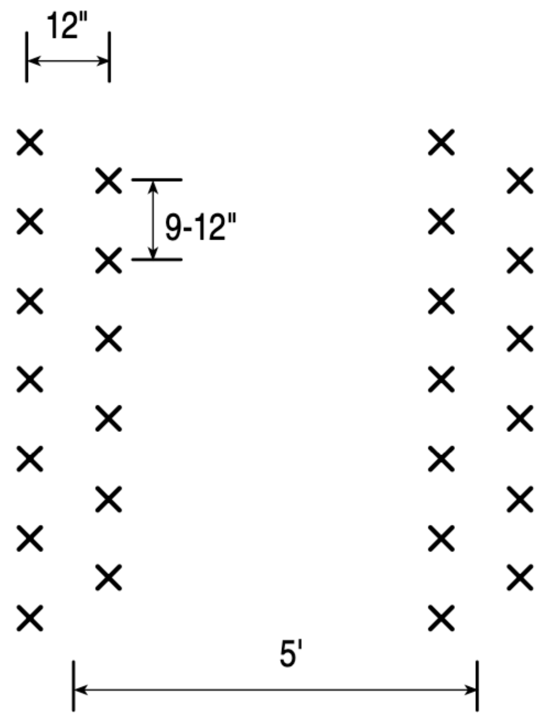


Figure 4-4. Spacing diagram for the annual plasticulture system.

Dormant Crowns

Dormant crowns are often planted mid-June to early July. Planting later than this will reduce the quality and survival of the plants from having been in storage too long, and plants may not develop enough crowns prior to winter. While planting earlier (April or May) can increase plant growth and survival, it can result in excessive runner growth because much of the development will occur during the long days and high temperatures of summer, which stimulates runner initiation.

For dormant crowns, a simple planting tool made from a 16 inch long, ⅛ inch thick, 1 ½ inch wide piece of flat bar can greatly speed up planting. The bar should be bent at 90° about 4 inches down from the upper end to form a handle. Similar tools can also be purchased (photo 4-32). The planting end should be filed to create a shallow notch across the width, with the edges smoothed. The crowns are placed on the plastic with the end of the roots over the planting mark. Placing the notch of the planter just in from the end of the roots, gently push the end of the planter straight down through the plastic mulch and into the soil, taking the roots and crown with it.

Photo 4-31. Two rows of strawberry plants on black plastic mulch (K. Orde).

Photo 4-32. Planting tool for planting dormant bare rooted crowns (D. Handley).

Photo 4-33. Correct planting of a dormant crown into plastic mulch (K. Orde).

Photo 4-34. Plug plants being planted in plasticulture system in Quebec, CAN (D. Handley).

Photo 4-35. Dibbler wheel used to mark the correct plant spacing and create holes for planting (D. Handley).

Photo 4-36. Runners being removed from plants that are growing in the plasticulture system (D. Handley).

When the top of the crown is just above the soil line, hold it in place and gently pull the planter straight back up, leaving the crown in place (photo 4-33). Be sure not to place the planter higher up on the root system when pushing the crowns into the soil. This will result in folding the roots, or "J-rooting", which will stress the plants and may kill them. Also, be careful to avoid hitting the irrigation lines with the tool. Once the plants are in place, they should be watered in to reduce stress and stimulate new root growth.

Plug Plants

Plugs should be planted before mid-September, ideally in August or early September (photo 4-34). In the past, it has been a challenge to obtain plug plants early enough for planting, but this may change with increased plant availability. Plug plants are available well into the fall for planting in southern locations, but planting after early-September, or even late-August in northern locations, is unlikely to allow the plants adequate time for establishment and flower bud initiation before winter sets in. Using rowcovers or low tunnels over the plants in the fall can help extend the growing season and improve bud set for next spring.
For plug plants, larger holes are needed, and a hand trowel or dibble may be useful for cutting the plastic and make holes for the plugs. For larger plantings, a water-wheel or dibbler type transplanter can be adapted to properly space and plant the plugs (photo 4-35). Irrigation immediately following planting and for several days is critical for good establishment of plug plants.

Fresh Dug Plants

Fresh dug plants should be planted from late July through August, depending on their availability from commercial nurseries. Plug plants are usually not available until September, although earlier dates may be possible by special arrangement with a nursery.

Care After Planting

Flower Removal

For beds established with dormant crowns or fresh dug plants, all of the flower blossoms that emerge shortly after planting are pinched off. This reduces stress on the newly planted crowns, improving plant vigor and leading to better yields next year. However, in an effort to offset the high initial cost of this system, some growers let these flowers, which were initiated in the nursery the previous fall, set fruit. This crop is usually quite small, but it may bring in a small return beyond its harvest cost. However, the resulting stress on the plants may have an impact on next season's crop. Beds established with plug plants will not flower until the following spring.

Runner Removal

Runners will begin to emerge on beds planted with dormant crowns or fresh dug plants several weeks after planting, stimulated by warm temperatures and long day lengths. All runners should be removed from the plants to improve plant vigor and to prevent the runners from rooting in the planting holes and along the edges of the mulch (photo 4-36). Left to root, the runner plants will behave as weeds, competing with the planted crowns for light, nutrients and water, and interfering with spray applications.

The runners may be removed with clippers, scissors or knives. Ear tag removers, plastic handles with a hook on the end which houses a razor blade, are inexpensive and work very well for this task (photo 4-37). Prohexadione-calcium (Apogee), a chemical that can reduce runner production, is allowed for use on strawberries in Canada but has not yet been registered for strawberries in the U.S. Removal of runners can significantly increase yield and fruit quality, as well as improve harvest efficiency and pesticide efficacy. However, the labor costs of hand removal are very high and thus have a significant impact on the profitability of the planting. In other warmer plasticulture growing regions, the plants are grown during the fall and winter months when strawberry plants produce few, if any, runners, and therefore growers don't have to contend with this cost.

Nutrition

By incorporating much of the strawberry's nutrient needs prior to planting, little if any additional fertilizer should be needed for the first 2–4 weeks. Once the plants have leafed out, they may use up to 3 lbs/acre nitrogen per week, and also have high demands for potassium and/or magnesium, depending on soil type.

These needs can be addressed with soluble fertilizers applied through the drip irrigation system. However, plant nutritional needs may be quite a bit lower than this. If plant vigor, leaf color, leaf size and petiole length are good, chances are that little, if any, fertilizer is required. The objective is to produce a large, multi-crowned plant without runners before winter. It may be helpful to take leaf samples for analysis to determine actual nutrient status. Contact your Extension service or soil lab for details on leaf tissue testing and fertigation.

Once plant growth begins the following spring, light applications of fertilizer may be applied through the drip irrigation system to provide available nitrogen, phosphorus, potassium, magnesium and boron; all important for early growth and fruit development. However, only 10–25 lbs/acre of actual nitrogen per acre is recommended prior to harvest (e.g., 3 ½ lbs/acre nitrogen per week, for 8 weeks) to prevent excessive vegetative growth and fruit rot problems. Boron applications should not exceed a total of 2 lbs/acre over the season to prevent toxicity problems.

Irrigation

Pay close attention soil moisture throughout the growing season. Overhead irrigation is best during the first few days after planting for fresh dug and plug plants. After that, beds should stay moist but not wet. 1–2 inches of water per week, applied through the drip system should be adequate, but regularly check soil moisture to determine the plant's needs (see Chapter 6).

Winter Protection

A long, cool, sunny fall will encourage strong crown growth and flower bud initiation. Rowcovers can be used to extend the fall growth period and for winter protection (photo 4-38) (See Chapter 5 for more about rowcover and low protection). Winter protection is essential in states north of the Carolinas, and rowcover is typically used for winter protection instead of straw. Lightweight (0.5–0.75 oz) rowcovers can be applied from early September to early October to encourage late-season growth. Once the plants have gone dormant in the late fall, a second layer can be added to improve winter protection, or replaced with a thicker one (1.25 oz or heavier) to provide winter protection. These covers stay on until spring. Lighter weight covers can stay on until flowers start to emerge and should then be removed to encourage pollination. Heavier covers should be removed earlier, as soon as growth starts, or they may delay new growth by not allowing adequate light through to warm the plants or for photosynthesis.

Rowcovers of the same weight (oz) are often manufactured using different techniques and materials which result in different light transmission properties. Emerging research shows that because of this, rowcovers of the same weight but different brand may differ in temperature underneath. While low temperature protection is important, there is evidence that light transmission is beneficial to plant survival and subsequent yield. Research on the effect of different rowcovers on yield and plant survival is currently underway in the Northeast; check for updates on this topic. If multiple rowcover weights or brands are used on-farm, consider monitoring temperatures and/or keeping records on what was applied and the perceived outcomes.

Second Year Management

Spring Frost Protection

The use of black plastic and rowcover will stimulate early growth in the spring, sometimes weeks earlier than matted row beds. While this may lead to an early harvest, it also increases the risk of frost injury to the flowers. Be prepared to protect the flowers from frost with rowcovers and overhead irrigation (see Chapters 5 and 6). Preventing frost injury is one of the most significant challenges of the annual plasticulture system.

Harvest typically begins about 3 weeks after bloom. Harvest in plasticulture beds often begins 2–3 weeks earlier than matted row beds. Plants should be harvested 2–3 times per week, sometimes more often, to prevent fruit from becoming overripe. Watering between harvests can help maintain fruit size through the harvest period and prevent fruit from becoming overheated on the black plastic mulch. Train pickers not to walk on the beds or kneel on the edges as this will damage the mulch, creating wet pockets and weedy spots in the beds.

Renewing Plasticulture for a Second Fruiting Year
Some growers will retain plants into a second fruiting year. Similar to the matted row system, if plants are kept beyond the first fruiting year, plants should be renovated. To stimulate new growth while removing old growth, the plants are mowed off just above the crowns shortly after the harvest season is finished (photo 4-39). The debris is swept off of the beds and removed from the planting or tilled into the soil between the beds. The beds are fertilized through the growing season (1–2 lbs/acre nitrogen per week), and runners are removed as they appear. Winter protection is carried out as in the planting year. While the renewed beds will produce again for a second season, the fruit size and yield are often noticeably smaller, and the disease and weed problems become more challenging. In addition, controlling runners becomes even more labor intensive during the second growing season because the plants are larger and have more time to produce them. Overall, harvest seasons beyond the first year tend to be less profitable, but may be viable if the additional labor cost and reduced yield can bring a higher net profit than re-planting.

An alternative to keeping the planting in a plasticulture system and removing runners all summer, is to pull the plastic after the first fruiting year and convert the planting to a matted row. A variation on this is to plant into biodegradable plastic in year 1 so that plastic does not need to be removed when the planting is converted to matted row in year 2. However, biodegradable plastic may be less effective at suppressing weeds and in some locations, can leave plastic residue in the field.

If plants are not kept for a second fruit season, the strawberry plants can be removed and warm-season vegetables, such as cucumbers or lettuce, can be transplanted into the plant holes to reuse the plastic mulch, before removing plastic and plowing the beds down in the fall.

Day-Neutral Strawberry Production

Day-neutral strawberries are less sensitive to day length than short-day varieties and will flower and produce fruit during the summer and fall of the planting year, and again the following spring (figure 4-5). The summer and fall crops offer growers the opportunity to market off-season fruit, potentially extending the strawberry season from 5 weeks to 3-–5 months (photo 4-40). Day-neutrals can provide expanded marketing possibilities, especially for roadside markets, groceries and restaurants. Prices for off-season fruit can be 2–3 times greater than the June-July crop, but timing of the harvest and labor needed to manage the crop can prove challenging for diversified growers. The harvest of day-neutral varieties is spread out, as opposed to the concentrated ripening of the June-bearing crop, extending over several weeks from mid-summer through fall, with equivalent amounts of fruit. Therefore, these plants are not as well suited to pick-your-own (PYO) marketing, although some growers have used them to expand other fall PYO markets, such as apples, fall raspberries and pumpkins. The fall harvest season can be extended further by protecting the beds from early frosts with rowcovers or plastic tunnels (see Protected Culture Production) (photo 4-41).

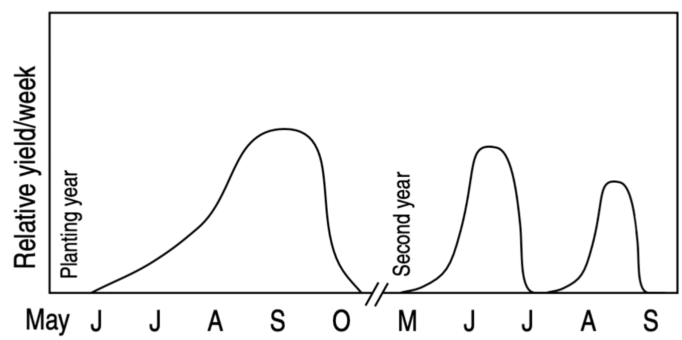


Figure 4-5. General production cycle of day-neutral strawberry plants.

Synopsis

Day-neutral strawberries should be grown in a plasticulture system in much the same manner as the annual plasticulture system for June-bearing strawberries described above, with the caveat that dormant crowns are usually planted very early (late April to early May) for the earliest and highest fruit yields in the planting year. Dormant crowns can be started early in a greenhouse in plug trays or pots and transplanted into the field in the early-spring for an even earlier onset of fruit and greater first year yields (than dormant plants).

Photo 4-37. Ear tag removers are an efficient tool for runner removal (K. Orde).

Photo 4-38. Row covers used for winter protection in a plasticulture field (K. Orde).

Photo 4-39. June-bearing plants following renovation (D. Handley).

Photo 4-40. Fruit from day-neutral plants on November 10 (M. Pritts).

Photo 4-41. Day-neutral fruit from low tunnels in the late fall (M. Pritts).

Photo 4-42. Low tunnel covering day-neutral plants (K. Orde).

For dormant crowns, harvest should begin in mid- to late July. For crowns started early in the greenhouse that are planted at actively growing plants, harvests may begin by early-June. Fruiting continues well into the fall, especially if frost protection and season extension strategies are employed. Following harvest, the planting can be removed or may be overwintered for a second-year crop.

Bed Preparation and Planting

Bed preparation should follow the same guidelines as described for annual plasticulture above, including raised beds 6–10 inches high and 18–42 inches wide, depending on how many rows will be set on each bed, and covered with black plastic mulch. Prior to laying the plastic, 30 lbs of slow-release nitrogen should be banded into the beds just below and to the side of the plant rows, and 1 drip line for each row of plants should be placed on the bed surface.Plants should be spaced 8–12 inches apart within rows, with 9–18 inches between rows on the bed, depending on the number of rows per bed. The planting tool described for dormant crowns in annual plasticulture above works well for this, but mechanical transplanters may be able to do a satisfactory job. Plants should be watered in well immediately after planting, especially potted or plug plants.

Care After Planting

Flowers that appear for the first 4–6 weeks after planting should be removed to reduce plant stress and encourage good root establishment. Likewise, any runners that appear should be removed to promote strong growth of the fruiting plants. Research with the varieties Albion and Seascape found that total and marketable yields tend to be greater from plants when runners were removed regularly (weekly or monthly), than when runners were removed once per season or not at all. The chemical suppression of runners using the plant growth regulator prohexadione-calcium is permitted in Canada, but the chemical has not been approved for this use in the United States.

Irrigation throughout the growing season is critical to assure good growth and yield. Using an irrometer or other soil moisture reading device is strongly encouraged to determine the best timing and amount of water to apply (see Chapter 6). Strawberry plant growth, and especially sugar content in fruit, is sensitive to heat. Overhead irrigation may be used to cool the plants, especially when fruit is present during hot weather. Running the sprinklers for a few minutes every hour can significantly reduce temperatures around the plants through evaporative cooling. Allow the plants to dry between applications to prevent the development of fungal diseases.

Nutrition is also critical to support good growth. Plants may require as much as 7 lbs N/acre/week, applied through the drip system, depending on variety and soil type. Plant demands for potassium and calcium are also high. These may be applied through the drip system or as foliar applications as needed.

Pest management can pose an increased challenge for day-neutral berries because they flower and fruit late in the season when pest populations are high, and the prolonged flowering-fruiting period can make it difficult to safely and effectively time pesticide applications. Tarnished plant bug, two-spotted spider mite, spotted wing drosophila, and oriental beetle grub management can be especially difficult (see Chapter 8). Be aware that some pesticides have preharvest intervals that will prevent consumption and sale of fruit for a period of time after application. Prolonged high temperatures can cause day-neutral strawberries to revert to a standard, or short-day growing habit, such that they produce few, if any, flowers, but lots of runners. Evaporative cooling with overhead sprinklers during hot days can help alleviate this form of heat stress.

Overwintering and Second-Year Production of Day-Neutral Beds

Traditionally, commercial day-neutral beds are treated as an annual crop, i.e., they are plowed down after harvest is complete in the fall and replanted in the spring. If kept over the winter, the beds will flower and fruit similar to a June-bearing bed the following spring. Depending on location and winter protection strategy, flowering and fruiting may be earlier than the June-bearing crop and it is possible to keep the planting beyond the initial spring season.

Fruit quality and yield in the second year will depend highly on the variety, plant survival, and health. Emerging research in the Northeast has found that some varieties have the capacity produce greater yields in the spring of the second year than during the entire first year of production and that there is great revenue potential from overwintering a crop. Keep in mind that if the day-neutral crop comes on at the same time as the June-bearing crop, there will not be a price premium for the crop, as supply will be at its peak at this time. If earliness is desired, low tunnels have been effective in promoting the earliness of fruiting in some years.

Winter hardiness in day-neutral can vary by year, overwintering strategy, variety, and is probably impacted greatly by the management of the crop the previous year and the environmental conditions of each winter period. In a recent study in the Northeast, San Andreas and Seascape tended to have high plant survival rates (> 96% during the 2 year study), higher than Monterey and Portola; Albion was intermediate. Researchers found that the same variety could have poor survival in 1 year, and good the next.

If the planting is kept for a second summer/fall crop, beds should not be renovated in the same fashion as June-bearing varieties, i.e., the leaves should not be mowed, and the plants should not be thinned after early summer fruiting. Runners should be removed during the summer, and this will be labor intensive. The plants will produce many more runners in their second year. Each plant will also have many more crowns in the second year, and multi-crowned plants tend to produce smaller fruit. By the end of second season harvests, the accumulation of weeds and other pests usually make the beds unviable for a third season.

The bottom line is that in many situations, day-neutral strawberries may be most successful when grown as an annual crop. However, if there will be a need for more strawberries the following spring, beyond what plantings of June bearing varieties will supply, then it may be worthwhile to carry them over for 1 winter. In some cases, they may be more productive in the second year, but this should not be the expectation.

Protected Cultivation

In temperate climates, not only is the growing season short but rain and hail threaten the marketability of fragile strawberry fruit and can cause significant crop loss if they occur during the height of the season. These environmental factors put growers in cold temperate climates at a competitive disadvantage with growers from other regions who can supply the fresh market more easily and consistently with less crop loss. Protective structures that modify or control the environment can offer many benefits, including:

- The exclusion of precipitation and dew, which reduces disease incidence and spread, and eliminates fruit directly damaged by rain or hail.

- Earlier and/or longer fruiting seasons; effectively extending the period of the year when locally or regionally produced fruit are available.

- Increases in marketable yield and fruit size, as well as a longer post-harvest shelf shelf-life of fruit.

- Improved labor ergonomics (in the case of tabletop or gutter production).

- The ability to utilize space that cannot used for in-ground crop production (such as locations with poor soil quality).

There are challenges to protected culture, including the need to precisely manage irrigation and fertilizer applications, as well as heating and cooling, unique pest challenges, and overall higher production costs.

Growing strawberries under cover may not extend the season in all cases. Many varieties of strawberry are daylength sensitive and require synchronous exposure to cool temperatures and short daylengths to initiate flower buds. If plants are kept too warm, they may not initiate flowers even when daylengths shorten. Shorter days means that plants receive less light, so they may not grow well even under ideal temperatures. Thus, consideration has to be given to match the daylength response of the varieties with the environmental conditions of the protected structure.

Nevertheless, strawberries have been grown in greenhouses and under plastic-covered structures for many years, especially in northern Europe and Japan, and in Italy and Spain, where high tunnels and hoop houses are ubiquitous. The expanse of plastic tunnels in Huelva, Spain can be seen from space, providing visual evidence that they can be economical and effective.

Plastic Covered Tunnels

Plastic-covered protective structures are a form of modified environment agriculture and are available in many shapes and sizes. Their cost and level of control over the growing environment vary significantly.

Low Tunnels

The term **low tunnel** refers to small plastic-covered tunnels that typically straddle 1 bed row in the field and measure 2–4 feet tall and wide (photo 4-42 and 4-43). Components (hoops, grounding stakes, end anchors) are manually installed in the field, and can be relatively easily assembled, disassembled, and moved to cover different areas.

Low tunnels are widely used around the world for strawberry production, especially in areas where there is a high risk of precipitation during the fruiting season. In a plasticulture system, gray mold (Botrytis cinerea) can largely be eliminated through the use of low tunnels, and low tunnels eliminate water damage and soil splashing on fruit. Sides can be raised and lowered to manage temperature. Research in the Northeast has found that low tunnels consistently increase the percent marketable yield compared with open field production, and that the protection from precipitation can lead to both 1) greater marketable yields following individual weather events, and 2) greater season-long marketable yields during a rainy season. On one occasion, researchers reported that following a rain event, only 2 percent of fruit yield was marketable from traditional unprotected beds, but nearly 80% was marketable under low tunnels. When combined with certain day-neutral varieties, low tunnels can allow for earlier harvests in the spring and later harvests in the fall. They may also decrease runner production from plants growing on black plastic mulch; the extent to which varies by variety.

Low tunnels can be custom-made using widely available materials or purchased as a commercial system. Proper installation and management are necessary to ensure the structures are user-friendly and sturdy, and that temperatures do not become excessively high inside tunnels during the summer months. See this Low Tunnel Management Guide for specific management considerations, and Chapter 14 for budgeting considerations.

Walk-in Tunnels

Walk-in structures such as **high tunnels**, **caterpillar tunnels**, and **hoop houses** are large plastic-covered structures that typically cover multiple rows of in-ground beds, gutters, or containers. The structures vary substantially in height, size, and style, and can have a variety of different features, heating systems, exclusion netting, or tracks for moving the tunnel from one area to an adjacent one. Tunnels can be single or multi-bay (sometimes called Haygrove® or gutter-connected) (photo 4-44), and have ends made of plastic, wood, curtains, or doors. The plastic film that covers tunnels can be a single or double-layer; the latter of which is often inflated and can provide improved heat retention.

These larger protective structures offer excellent protection from precipitation and added control over the growing environment. They can accelerate harvest by 1 month in northern climates and promote continued fruiting in the fall months (plant type dependent). Harvesting can occur regardless of the weather outside. When temperatures are very low, plants can be covered with rowcover inside the tunnel for additional temperature protection.

Greenhouses and Controlled Environments

Glass and plastic-covered structures with controlled, high-technology environments are known as controlled environment agriculture and allow for year-round production of fruit by carefully regulating temperature, day length, lighting, and nutrient inputs. The relatively stable environment of a greenhouse is also conducive to biological pest control that can reduce the need for pesticide applications. Greenhouse systems often recirculate

Photo 4-43. Full bloom under a low tunnel (K.Orde).

Photo 4-44. Multi-bay plastic covered tunnels (K.Orde).

Photo 4-45. Above-ground tabletop system with legs (Sue & Charlotte Reed, Benty Farm Tearooms, UK).

Photo 4-46. Gutters hung in a greenhouse (K. Orde).

Photo 4-47. Outside tabletop production with plastic covering a single row (K. Orde).

Photo 4-48. Tunnel covering multuple rows of tabletop production (Sue & Charlotte Reed, Benty Farm Tearooms, UK).

water and nutrients to minimize environmental impacts and optimize resource use. The objective of these intensive systems is to produce a high-quality fruit for a niche market. Strawberries are expensive to produce by these means, and growers who use high-tech systems are unlikely to compete with growers in Florida or California on the basis of price. Rather, the high quality of the product is the selling point. That said, with strong consumer demand for regionally produced fruit, there are wholesale opportunities for those able to produce at scale.

Tabletop, Gutter, and Trough Systems

There are many examples of tabletop, gutter, and trough systems across the world. These systems can be installed in controlled, modified, or even unprotected environments. Some systems have legs (photo 4-45), and others are hung (photo 4-46). If hung, it is important to ensure that the structure's frame can support the load. In locations where precipitation is likely, it is common to protect plants with plastic by covering individual (photo 4-47) or multiple rows (photo 4-48). There are numerous systems and on-farm customizations are common.

Using Bags and Pots

Bags, pots, and other containers or vessels can also be used to grow strawberry, particularly in protected culture (photo 4-49; photo 4-50). Elevating containers on tables will facilitate more comfortable harvesting, and white containers will keep soil and root temperatures cooler than black containers. White pots tend to be more costly than black pots, making white grow bags an attractive alternative. Research shows that deep containers tend to be better for strawberry.

Vertical Growing Systems

Vertical growing systems have been used with varying degrees of success in the Northeast (photo 4-51). Since plants are essentially stacked, shading will occur that makes maintaining uniform moisture levels between top and bottom plants difficult. There are some examples of rotating gutter systems, which alternate the plants on the top or bottom to promote uniformity.

Important Considerations

It is important to select the daylength (short-day, day-neutral, etc.), plant type (dormant bare-rooted, plug, conditioned, etc.), and system, in coordination. Certain plant types may only be available from nurseries during specific times of the year and may even require preparation or conditioning. Day-neutral varieties are well-suited for high tunnels or other modified environments as they will begin producing fruit in a matter of weeks or months after planting and will continue fruiting. Planting plugs instead of dormant plants will decrease the time between planting and fruiting. Conversely, growing short-day plants in a high tunnel using the traditional in-ground system will tie-up tunnel space for nearly a year prior to any return. However, there are ways to reduce this time and still use short-day plants in a rotation (see Forcing Strawberries). In a greenhouse, where supplemental heating or lighting can be provided, multiple crop cycles can occur in a given year, and using a combination of short-day and day-neutral varieties may be the best way to maximize space.

Substrates

Appropriate substrates for growing strawberries in trays or pots include peat, perlite, vermiculite, coconut coir, and well-aged bark. For loose-filled pots, bags, or other containers, a 2:1 peat:perlite mix or 1:1:2 peat: coir: perlite mix have been found to be good options. Coir used to require thorough rinsing to reduce residual salts from processing, but some coir slabs now come washed and conditioned, and may even be loaded with a starter fertilizer. Research on the best ratios of media is on-going. Discuss custom mixes and slabs characteristics with suppliers directly.

Strawberry plants grown in substrate require precise amounts of nutrients and water, so fertigation should be automated as much as possible. On hot days, water may be required more than once an hour depending on the substrate and container size. Strawberries require a complete nutrient solution, as well as an acid to adjust the pH as needed. Nitrate-based fertilizers should be kept in a different tank than sulfur-based fertilizers and alternately applied. Target pH for the fertilizer solutions should be 5.5. Aim for 150 ppm N during vegetative growth and 100 ppm N during fruiting. The electrical conductivity (EC) of irrigation water should be low (< 0.6 mS/cm) without fertilizer and no higher than 1.8 with fertilizer, with a drain EC of <3.6. Runoff should be 15–20% of the amount of water applied. Plants grow better when irrigation water is warm (75˚F). Growers contemplating substrate culture should participate in a workshop designed specifically for this method of production as there are many issues to consider.

Plastic Film Selection

Agricultural films vary in their transmission profiles; meaning, they can transmit different levels and types of solar radiation. The regions of the spectrum that impact plants are:

- Ultraviolet (UV) Radiation (280–400 nm): UV light has a shorter wavelength than visible light. UV radiation that reaches earth's surface includes UV-B (280–315 nm) and UV-A (315–400 nm). Increased plant exposure to UV can initiate the production of protective compounds in the plant and fruit (including anthocyanins and the phenolic contents), and even hasten color development. Since some insects use UV radiation for navigation, blocking this radiation can decrease the presence of certain pests, but may provide refuge to others.
- Photosynthetically Active Radiation (PAR; 400-700 nm): PAR is the primary region used by plants for photosynthesis and growth. Red and blue light is mostly absorbed while much of the green light is reflected.
- Far-Red (FR; 700-750) and Infrared/Near-Infrared Radiation (NIR; 700-1100): the FR and IR/NIR ranges are made up of longer wavelengths that are heat-generating. Films that reduce or block these wavelengths can help create cooler growing environments. However, FR is important for fruiting. Films also exist that contain materials to block longwave infrared radiation emitted from the ground at night, which may assist with nighttime heat retention.

Strawberry plants tend to perform well under films that transmit high percentages of all wavebands (UV, PAR, FR, and IR/NIR). Earlier ripening and even higher yields have been reported under highly transmissive films, but fruit size is occasionally greater under films that reduce UV transmission. However, emerging research suggests that the characteristics of films should be matched with plant type. Researchers found that compared with dormant crowns, plug plants performed better under films that reduced the heat-generating FR and NIR radiation.

Additives that modify the transmission of films (UV blocking, IR reflecting, light diffusing, anti-condensate) will often add to the cost of films. One should keep in mind that protective structures will automatically reduce light transmission compared with the unprotected environment. However, recent research suggests that if infrared radiation is reduced so that temperatures under plastic covers are lower, then plants can tolerate significantly lower light levels.

Photo 4-49. The day-neutral variety 'Albion' in white grow bags in a high tunnel (K. Demchak).

Photo 4-50. Compost sock planted with strawberry and equipped with drip irrigation (D. Handley).

Photo 4-51. Vertical strawberry growing system (D. Handley).

Lighting and Heating

Because the weather is cloudy and daylengths are short for much of the winter in the Northeast and eastern Canada, supplemental lighting is necessary for winter production. Strawberries need about 15 moles of light per day to produce a good crop. Automated systems can be designed to come on at the end of each day and provide the difference between 15 moles and what the sun provided. Lighting costs can be reduced significantly by providing supplemental light only at night, when off-peak electricity can be used. Short-day strawberries are unaffected by daylength once they are flowering. Day-neutral varieties are less responsive to daylength and light supplementation is not likely to affect the fruiting pattern. However, there is some indication that longer days promote flowering in some day-neutral varieties and that lights with supplemental FR radiation may increase yields and fruit size.

Strawberries thrive at lower temperatures than most houseplants. Maintain a 75˚F/60˚F day/night temperature differential and a 65/85 humidity differential. Lower humidity during the day and higher humidity at night is necessary to prevent calcium deficiency and ensure pollen germination. Controlling heat in greenhouses and high tunnels during the summer months is a challenge as when temperatures become too high, fruit set will decline.

Forcing Strawberries

Forcing strawberries to flower and fruit out-of-season has been practiced for many years. A Cornell University Extension bulletin written by Liberty Hyde Bailey in 1897 discusses forcing strawberries in greenhouses. Bailey states that "the attempt was so successful that the methods which were employed in raising the crop are here detailed." In his research, Bailey rooted strawberries in pots outdoors. The potted plants were kept in a cold frame until they were exposed to short days and cool temperatures in fall, then moved into a heated greenhouse at intervals beginning in late December. Flowers were pollinated by hand, and the first crop was harvested from May 6 through May 16. Each plant produced an average of 6 large berries, or 1 quart per 3 square feet of bench space. Interestingly, the price of these berries in 1897, $2/quart, is approximately $28/quart today.

Bailey was describing a waiting-bed system used to force short-day varieties. These plants are cold-stored for up to 8 months after being grown outdoors and are moved/transplanted into a greenhouse after exposure to short days and cool temperatures. Transplanting can begin as early as late December. By staggering planting dates throughout the winter, a long harvest season can be realized. To create waiting bed plants, set dormant crowns into pots in May or June, and allow them to grow outdoors until early November. Remove runners and flowers at regular intervals and fertilize them well. These short-day plants initiate flowers in autumn and need just a short period of cold temperatures to break dormancy and grow.

Plants are stored in a cold room at about 28–30˚F for another month. They are ready to fruit once they are moved into a warm environment. 10 weeks before fruit is desired, move them into the greenhouse. Plug plants started in early summer can be used in a similar manner.

Yields of 12 oz/ft² during a 3 week fruiting period are reasonable with this system. A major advantage of using short day varieties is that pest pressure is usually low because whole plants are cycled through the greenhouse every 12–14 weeks. The disadvantage is that the system requires a steady supply of waiting bed plants that are generally discarded after fruiting.

Day-neutral varieties are an alternative to the waiting-bed system in which the same plants are retained for several months and not replaced frequently. Obtain dormant day-neutral runner plants from commercial nurseries in late-autumn and plant them directly into the greenhouse or make plug plants during the summer from runners from mother plants. Mother plants in troughs exposed to high temperatures will runner more profusely than plants grown at ideal temperatures for fruiting. Runner tips hanging over the edge of the troughs can be cut off, stuck in a peat plug, then misted to encourage rooting.

Day-neutral plants will continuously flower and fruit under the short photoperiods of winter and the long photoperiods of summer as long as the temperature is not too cold or hot (45–85˚F). Supplemental light up to 15 moles per day will enhance flowering and fruiting during winter months. This can be an opportunity to use electrical power during off-peak hours. The fruiting season for individual plants can be several months as opposed to several weeks for short-day varieties.

Day-neutral strawberry transplants should be planted into soilless media and deflowered for 2 weeks to allow for good establishment. Remove runners from the plants periodically, although runnering lessens when plants begin to bear fruit.

Pollination

When flowering is early or plants are in a netted or closed tunnel, the addition of bumble bee hives for pollination may be necessary. Studies show that even in open environments, the addition of pollinators tends to increase fruit set. A leaf blower can also be used to support pollination.

Aquaponics

Producing fish such as tilapia in a large tank and then using the nutrient-rich water to fertilize strawberries has great appeal. In theory, such a system can be quite productive, and nutrients are recycled rather than wasted. In practice, the fish prefer a warmer temperature than the strawberries and the strawberries prefer a lower water pH than the fish. Coupling these two systems is challenging, and additional nutrients need to be added to the variable fish effluent to satisfy the strawberry's nutrient needs.

Further Reading & Citations

Orde, K., B. Sideman, M. Pritts, and K. Demchak. 2018. Low Tunnel Strawberry Production Guide. University of New Hampshire Cooperative Extension Publication.

Orde, K. and R. Sideman. 2021. Winter Survival and Second-year Spring Yields of Day-neutral Strawberry Are Influenced by Cultivar and the Presence of Low Tunnels. HortScience 31(1):77-88.

CHAPTER 5

Temperature Regulation: Mulches, Rowcovers, Frost Protection, and Evaporative Cooling

Strawberry growers can enjoy a full crop of berries only if they practice some type of temperature control during the year. This is especially important during the winter and early spring when flowers are susceptible to cold temperature damage and frost. Excessive summer temperatures inhibit growth as well. This chapter describes strategies for temperature management at critical stages during the year.

Winter Temperatures and Cold Injury

Cold temperatures coupled with high winds can injure strawberry plants during winter, especially if the plants are grown on raised beds and/or not covered with an insulating layer of snow. Strawberries are considerably less cold-tolerant than most other fruit crops grown in the northeast, but because the plants are low-growing and can be protected from the cold by snow cover or some type of mulching material, they can be grown on a commercial scale in northern regions.

The severity of winter injury incurred by strawberry plants depends on many factors, some of which have a much greater impact than others. The first group of factors relates to how much cold tolerance the plants develop. The variety, plant nutritional status, plant age, and autumn hardening conditions such as temperature, moisture, and light all affect a plant's tolerance to cold. Other factors directly influence the amount of injury during or immediately after the hardening process. These include the timing and severity of minimum temperatures, the rates of temperature change, repeated freezes, the amount of snow cover, the type and amount of mulch used, the length of time plants are covered with mulch, soil type, and the type of cultural practices being used (for example, raised versus flat beds). Each of these factors is discussed in more detail in the following sections.

Plant Acclimation and Cold Tolerance

Strawberry plants acclimate to cold over a 6–8 week period in the autumn in response to shortening day lengths and lower temperatures (figure 5-1 and 5-2). As part of this process, plants begin to accumulate starch in the crowns and roots to provide energy during the upcoming winter months. With most varieties, plant injury begins when the crown temperature (not air temperature) reaches 23˚F, and death can occur if the crown temperature drops to 4˚F. In some studies, death has occurred when the crowns have reached 10˚F. While the absolute lethal temperatures can vary, within this temperature range (4–23˚F), the risk of injury and yield loss increases proportionally with decreasing crown temperature.

Variety Hardiness

Differences in hardiness among varieties are slight—the crown temperatures at which injury occurs vary by only a few degrees. In some years, however, a few degrees may result in a substantial change in yield. Field observations and laboratory studies have shown that some of the hardier June-bearing varieties include Brunswick, Catskill, Cavendish, Honeoye, Jewel, Kent, Mesabi, Sable, and Sparkle. Because day-neutral varieties continue fruiting during the fall acclimation period, they do not accumulate as much carbohydrate before winter so their winter survival may be compromised if they deplete their reserves before spring.

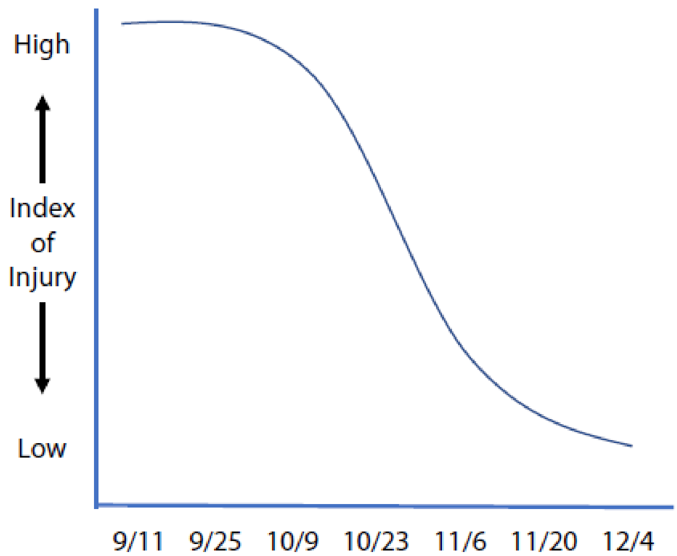


Figure 5-1. Seasonal acclimation of strawberries. Index of injury represents the degree to which plants are damaged by exposure to freezing temperatures.

Time of Injury

Although cold injury may occur any time during the late fall, winter, or early spring, it is frequently associated with lack of snow cover during winter. Plants are usually injured after the ground is frozen. Straw mulches that offer good protection when first applied lose much of their insulating value if they become matted down or filled with ice. Likewise, low areas in a field may collect standing water that will create a layer of ice if it freezes. Since ice is not a good insulator, the plants embedded in ice are more prone to winter injury.

Symptoms of Injury

Strawberry plants respond to winter injury in several ways, depending on the severity of the injury. Tissue discoloration or the degree of browning revealed by cutting crowns longitudinally is often used as a field indicator of the seriousness of injury (photo 5-1). Injury begins with browning of the cells at the base of the crown. As the amount of injury increases, the browning extends toward the top of the crown and becomes more intense in color. The last tissues to be killed are the leaf primordia (the small leaves that are just beginning to develop in the crown) and the vascular tissue. A slight amount of browning may cause reduced leaf size, deformed leaves, fewer flowers, and/or smaller fruit. These latter symptoms may go undetected if the injury is mild.

Controlled freezing studies have shown that reduced yields can occur even with only a slight amount of browning. In a laboratory study using Catskill, an older but hardier variety, injury was detected at a crown temperature of 23˚F, and the number of blossoms was reduced by about half at a crown temperature of 18˚F.

Photo 5-1. Winter injury to crown (D. Handley).

Snow

Strawberry plants must be protected from the cold in northern regions. Snow depths over 6–8 inches usually keep crown temperatures sufficiently warm, even when air temperatures drop as low as –25˚F. Although snow cover is by far the best protection, it is not dependable in most areas, so mulches are used to keep winter injury to a minimum. Cold, desiccating winds are extremely harmful to uncovered strawberry plants. Taking measures to reduce wind (for example, erecting snow fences) can also help avoid winter injury.

Mulching

Providing supplemental cover to plants in late fall is the most practical way to prevent cold injury.

Grain straw mulches (e.g., oat, rye, barley, or wheat) are the most commonly used protective cover for strawberry. Straw also helps hold the snow, particularly on raised beds where snowfalls are subject to drifting. During the production season, straw mulch prevents soil from splashing on the developing fruit, which reduces culls and the incidence of leather rot. Rye and sudangrass straw are satisfactory, but wheat straw is usually preferred because it is more resistant to compaction, and so retains insulating properties when wet. Oat and barley straw tend to break down quickly and provide less insulation.

Straw should be clean and free of any seeds. Strawberry growers often produce their own straw and bale it before seeds form. Straw mulch is applied over the tops of strawberry rows, usually with machines that chop the straw and spread the mulch. Newer machines can accommodate large, round bales rather than just small, rectangular bales. The objective is to cover plants with enough straw to prevent desiccation of the crown (photo 4-9). A minimum of 2–3 tons/acre (a 2–3-inch layer) is recommended in areas with regular snowfall and moderate temperatures, but 4–5 tons may be necessary in cold, windy climates or where plants are grown on raised beds (which tend to be colder).

Rowcovers (photo 5-2) can be used for winter protection in northern regions, especially for overwintering annual plasticulture strawberries. Using rowcovers for winter protection offers some advantages: they can be reused in the spring for frost protection (see below), and they may be easier to apply and remove than straw. Rowcovers allow some light to transmit to the leaves below, which can photosynthesize on warmer days. This can help the plants retain adequate carbohydrate levels that are slowly depleted when covered with an opaque material like straw. The diurnal fluctuation in temperature under rowcover is greater than under straw. Several companies manufacture covering materials. The most useful materials are spun-bonded with sewn seams; this allows for the construction of wide pieces. For winter protection, medium to heavy weight rowcovers (0.9–1.5 oz/yd^2) are usually used; it may be wise in colder sites to use 2 layers for additional insulation. Most producers that use rowcover still use straw, or a fabric weed barrier, between rows to control weeds and to keep berries clean during harvest.

Photo 5-2. Field in spring with rowcover applied (B. Sideman).

Mulch Application

Strawberry leaves are photosynthetically active well into late autumn (figure 5-2) and in early spring as well. Since straw mulch is opaque, it should not be applied it too early in the autumn or removed too late in the spring, as this compromises the plant's ability to manufacture carbohydrates. If mulch is applied too early, while the plants are in their hardening process, they may not acclimate properly. Straw should be applied after several frosts have occurred and when the leaves attached to the crown have begun to flatten. Mulch must be applied before temperatures become cold enough to cause injury and before snow cover makes applying it impractical. In most northern locations, this is usually late November. Delaying mulching until just before the ground freezes results in the highest yields. Many growers try to apply straw just before a late fall fall rain or snow event to reduce the chance of wind moving the mulch around the field.

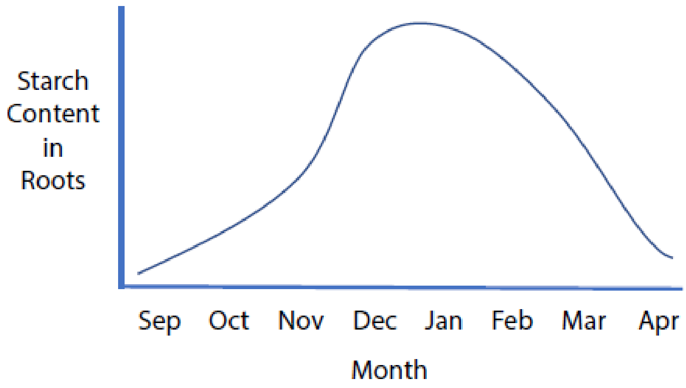


Figure 5-2. Seasonal pattern of starch content in roots. A higher starch content means that the plant has more energy reserves.

Mulch Removal

Mulches should be removed as soon as there are signs of new leaf growth in the spring, and once temperatures will no longer damage crowns. In most northern locations, this corresponds to mid- to late March. In a 3-year study where mulch was removed periodically over 6 weeks, the highest yields came from plants that had the mulch removed as early in the spring as was practical following snow melt (mid-March in northern New England). Removing mulch after April 15 may reduce yield significantly. Although the primary purpose of mulch is winter protection, it also keeps the fruit clean. Leave enough mulch around the plants so the berries will not touch the soil. The plants will grow through a light layer of straw. Placing mulch between the rows also helps control weeds, conserves soil moisture, adds organic matter over time, and makes picking more comfortable.

Care of Winter-Injured Plants

Cold injury reduces the number of fruit on a plant and adversely affects fruit size. Any additional stress suffered by injured plants during the fruiting year will magnify the problem. Once injury occurs, the number of fruit cannot be increased, but further losses can be minimized by providing ample moisture and controlling weeds, insects, and diseases. Supplemental fertilizer has little impact. Consider the severity of plant injury when deciding whether or not to renovate after harvest.

Early Spring Temperatures and Rowcovers

Synthetic spun-bonded rowcovers are a useful tool for growers who want to accelerate harvest with a portion of their crop (photo 5-2). Rowcovers allow light and moisture to penetrate but trap in heat, so the microclimate under the cover is favorable for early growth. With cool, sunny spring weather, rowcovers can accelerate flowering by up to 2 weeks. Furthermore, most studies have documented yield increases with the use of rowcovers. Using rowcovers on early varieties while leaving mid-season and late varieties uncovered extends the harvest season for the June-bearing varieties, in some years to as much as 6 weeks. An extended harvest season increases marketing opportunities and can also reduce risks of harvest losses due to spells of rainy weather during harvest.

Growers using rowcovers for winter protection should be aware that early-season growth will be enhanced under rowcovers, and the crop may be hastened. While this allows early fruit production, it also increases the risk of early-season frost. Those not prepared to manage early frosts should remove rowcovers promptly in early spring to slow down plant development.

Rowcovers can be used to promote early spring growth, even if straw is used for winter protection. If covers are to be used, the mulch must be removed from the plants early and replaced with rowcover. Early March is generally a good time to remove straw and apply the rowcover. If snow still covers the planting, then obviously it is best to wait until the snow has melted. Similarly, if unseasonably cold weather persists in early March, then wait for warmer weather before removing the straw.

Perhaps the biggest challenge with rowcovers is applying them. Do not attempt to apply them under windy conditions. The material must be firmly anchored around the edges. Many ingenious anchoring devices have been tried, but 1 sucessful option is using large U-pins and positioning a popsicle stick between the pin and the cover. The sticks will bend just enough to keep the cover from tearing, and they are inexpensive and easy to install.

In windier areas, sandbags are a good option. Some growers purchase UV- protected nylon bags, fill them with a small amount of gravel or sand and use them to anchor the rowcover every 6–10 feet. Rocks or aluminum irrigation pipe also can be used to help anchor edges.

Remove the covers soon after flowers appear, because if wind or bees cannot reach the plants, pollination will be reduced, and fruit will be deformed. Research has shown that rowcovers can reduce the incidence of tarnished plant bug damage, provided fields are not weedy. If the flowers open before tarnished plant bug adults emerge from surrounding fields, feeding on flowers will be minimal. Strawberry clippers will overwinter within strawberry plantings, especially if weeds are present, so monitor carefully for this insect if it has been a pest in previous years. Rowcovers can make looking for clipped buds difficult.

Rowcovers are increasingly being used in the late spring for frost protection, in place of (or in addition to) irrigation. See *Row Covers for Crop Protection*.

Covers can be reused several times, although it is difficult to roll the material back into a compact form. Before removing the covers from the field, consider spray painting the edges so they can be found easily. Careful handling and storage is essential to ensure multiple seasons of use. Some growers fold covers and wind them back onto large spools with a tractor-mounted winder; others accordion-fold in both directions for easy re-application. Labelling rowcovers clearly can save a lot of time and frustration. A word of caution—mice love to overwinter in stored rowcover.

The cost of rowcovers ranges from $800–$1,400 per acre (see Chapter 14). Although this may seem expensive, the cost is not that great if prorated over 3–6 uses. Some growers find that using rowcovers on at least a portion of their acreage is a profitable practice, because they receive a higher price for early berries and yields are generally higher.

Spring Frost Protection

Of all the factors that negatively affect strawberry production, frost is the most serious. Frost can eliminate an entire crop almost instantly.

Strawberries often bloom before the last frost, and if a frost occurs during or just before bloom, it can cause significant loss. The strawberry flower opens toward the sky, which makes it particularly susceptible to frost damage. A black rather than yellow flower center is an indicator of frost damage (photo 5-3).

Photo 5-3. Frost injury (right) to a strawberry flower (B. Sideman).

Critical Temperatures

Many factors affect whether flowers are injured by cold temperatures. Plants deacclimate and become more susceptible to cold injury when they experience warm temperatures. As a result, freeze events following a period of warm weather are most detrimental. Strawberry flowers are most sensitive to frost injury immediately before and after they open (see table 5-1). Prolonged tissue temperatures below the critical temperatures may cause injury. Soil absorbs heat during the day and releases it at night. Moist, dark soil has better heat-retaining properties than dry, light-colored soil. The presence of straw between rows can increase the incidence of frost injury, because it prevents soil from absorbing heat as solar radiation. If you plan to apply additional straw between the rows in spring, delay applying it for as long as possible before fruit set.

Table 5-1. Critical temperatures for strawberry tissues according to stage of development (source: Perry and Poling 1985). Many variables affect injury: duration of cold, growing conditions prior to cold, variety, stage of development, and many environmental conditions.

Stage of development	Critical temperature (˚F)
Dormancy (buds inside crown)	10˚F
Transition period (buds inside crown)	mid-teens
New leaf stage (buds inside crown)	upper teens
New leaf stage (emerged buds)	20–25˚F
Tight bud	22 ˚F
"Popcorn"	27–28 ˚F
Open blossom	30˚F
Fruit	28˚F

Monitoring Temperature

The forecasted temperature and the actual temperature on the farm will be different, especially at plant height. The small investment of quality thermometers for monitoring temperatures allows for informed decision-making, and should not be considered a superfluous expense. Since cold air falls to the lowest spot in the field, a thermometer should be located there. Place it in the aisle at the level of the flowers, exposed to the sky and away from plants. Air temperature measured at this level can be quite different from the temperature recorded on a thermometer near the house. Keep in mind that the plant temperature is often colder than the air temperature next to the plant.

Remote monitoring can be very helpful in knowing the exact temperature at one or more locations in a field, or in several fields. Combining temperature monitoring with alarm systems can help guide irrigation for frost protection. The options available for this purpose depend on whether there is wifi, cellular, or phone connectivity, or none of the above. The University of Vermont Agricultural Engineering program maintains a helpful resource listing remote monitoring options (See Further Reading).

Dew point measured in the evening is an important consideration in frost and freeze management because it is a good indicator of how low nighttime temperature will drop, and it is often considered a proxy for the night's low temperature. The dew point is the temperature at which moisture condenses from the air to form dew. Once dew begins to form, the air temperature tends to drop more slowly. Frequently, the night temperature drops to the dew point, but it does not go much below it. The dew point is related to relative humidity: when the air is humid, the dew point occurs at a higher temperature than when the air is dry. When the temperature is below freezing, the dew point is sometimes called the frost point.

Note that flower temperature is not necessarily the same as the air temperature. On a clear and calm night, the temperature of a flower can be lower than that of the surrounding air because radiational cooling causes leaves and flowers to lose heat faster than they receive heat through conduction from the air. Further, flowers near the soil may be warmer than those higher on the plant. It is possible for flowers to freeze even when the temperature is above 32˚F, particularly when the air is dry and the winds are calm. Frosts are unlikely on windy nights when the temperature is above freezing wind mixes the air, minimizing radiational cooling.

Frost vs. Freeze Events

While frost and freeze are sometimes used interchangeably, they actually refer to distinctly different events. Understanding the conditions of each is helpful in making the best management decisions.

A radiation frost, or **frost**, occurs under calm winds (<5 mph) and clear skies. Heat escapes from the earth's surface and the lighter warm air rises. A mass of heavy cold air settles close to the ground, and a warm air layer hovers 20–300 feet above, creating what is called an inversion. If the dew point of the cold air is above freezing, it's not likely that frost will form on plants unless the temperature is very close to freezing and plants are colder than the air, which can allow frost to form even when temperatures are not freezing. If the dew point is below freezing, a frost becomes more likely and when dew does form, it freezes and manifests as what we know as "white frost". Another less common type of frost is called **black frost** (also known as "invisible frost" or a "dry freeze"), which occurs when temperatures are below freezing but above the dew point. In this case, it would not be effective to wait for signs of frost before turning on irrigation, as temperatures may fall below critical temperatures without any sign of frost.

An advection freeze or **freeze** (also known as "wind freeze"), occurs when an air mass with wind >10 mph and temperature below freezing (<32˚F) move into the area. Often, these air masses are dry and significant in size, being 500–5,000 feet deep. It is more difficult to protect crops under these conditions, as air speeds greater than 8 mph can make overhead irrigation more challenging and multiple approaches may be required to protect plants. A frost/freeze event can also occur, which is a combination of frost and conditions with wind speeds 5–10 mph.

Protecting Plants from Frost/Freeze Events

Overhead Irrigation

Overhead irrigation is traditionally used for frost control, because wet flowers are protected during a freeze. As long as water is present on a flower, the temperature of the ice will stay at 32˚F, because the transition from liquid to ice releases heat. Strawberry flowers are safe from injury until their temperature falls below 28˚F. Because of this 4-degree margin, a strawberry field can be completely covered with ice and yet the plants will sustain no injury from frost.

The temperature of the applied water is usually greater than the temperature of the plants, and this serves to warm the flowers before heat is lost to the air. As long as water is continually applied to the plants, the temperature under the ice will not fall below 32˚ F. However, if insufficient water is applied to a field during a freeze, the plants might sustain more injury than they would if no water were applied.

Several factors affect the amount of water required to provide frost protection and the timing of application. At a minimum, apply water at 0.1–0.15 inches per hour. Choose a nozzle designed for frost protection; it should be designed to prevent freeze-up, with a head that rotates at least 1 cycle per minute. Water must be applied continuously to be effective. A water capacity of 45–60 gallons per minute (gpm) per acre is required to provide this much water.

The water application rate depends on both air temperature and wind speed (see table 5-2). Under windy conditions, there is less chance of flower temperatures falling below air temperature because of the mixing of air that occurs at the boundary of the flower. Winds are beneficial if the temperature stays above the critical freezing point but detrimental if the temperature approaches the critical point. Windy conditions accelerate heat loss from water, so more water is required for frost protection. Under extremely windy conditions, it may be best not to irrigate because the heat lost to evaporation can be greater than the heat released from freezing. Less evaporation (and cooling) will occur on a still, humid night.

Table 5-2. Water application rate (inches/hour) for a given humidity and wind speed.

		Wind Speed (mph)				
Relative Humidity	**Air Temperature (˚F)**	**0–1**	**2–4**	**5–8**	**10–14**	**18–22**
50%	27	0.10	0.20	0.30	0.40	0.45
	24	0.10	0.30	0.35	0.45	0.60
	20	0.15	0.35	0.45	0.60	0.75
	18	0.20	0.40	0.50	0.65	0.80
75%	27	0.05	0.10	0.20	0.25	0.25
	24	0.10	0.20	0.30	0.35	0.40
	20	0.10	0.25	0.40	0.45	0.60
	18	0.15	0.30	0.45	0.55	0.70

FROSTPRO model from North Carolina State University.

At flowering, the air temperature at which irrigation should start is normally between 31˚F and 34˚F but can be as high as 40˚F. The exact temperature depends on cloud cover, wind speed, and humidity. Admittedly, these numbers are conservative. Flowers can tolerate colder temperatures for short periods of time, and irrigation may be unnecessary if the sun is about to rise. Do not irrigate too soon, since pumping is expensive and excess water in the field can cause disease problems.

If the air is very dry (there is a low dew point), evaporative cooling will occur when water is first applied to the plants, so irrigation must be started at a relatively warm temperature. Table 5-3 shows the recommended temperature for starting irrigation at various dew points. Most detailed weather forecasts provide the current dew point.

On a clear, calm night, it would be wise to start irrigating if the air temperature falls below 34˚F, especially before 3:00 a.m., since flower temperatures could be several degrees colder. On the other hand, if conditions are cloudy, it may not be necessary to start irrigating until the temperature approaches 31˚F. If conditions are windy or the air is dry and if irrigation is not started until the temperature approaches 31˚F, then damage can occur due to the drop in temperature that occurs when the water first contacts the blossom and evaporates. Once irrigation begins, do not shut off until the sun comes out in the morning and the ice begins to belt off the plants.

Table 5-3. Dew point and corresponding suggested air temperatures for starting irrigation.

Dew point (˚F)	Temperature at which to start irrigation (˚F)
30	32
29	33
27	34
25	35
24	37
22	38
20	39
17	40

Rowcovers for Frost Protection

Rowcovers modify the influence of wind, evaporative cooling, radiational cooling, and convection (photo 5-4). Wind velocity is lower under a rowcover, so less heat is lost from the soil and less evaporative cooling occurs. Relative humidity is higher under a rowcover, so less heat is lost from evaporation. Convective heat loss and radiational heat loss are also reduced because of the physical barrier provided by the cover. Plant temperatures under a cover may eventually equal air temperature, but this equilibration takes longer than with uncovered plants. In other words, rowcovers may only provide a few degrees of protection, but they also buy time on a cold night, because flower temperatures fall more slowly under a cover. It is not uncommon to have several nights in a row of frost (or risk of frost), where irrigation would be warranted. Many sites do not have sufficient water to irrigate this frequently, or have soils that would become waterlogged by nightly irrigation. For this reason, many producers are starting to use rowcovers for frost protection, in colder climates as well as in the mid-Atlantic and southern states.

Heavy weight rowcovers (as heavy as 2.0 oz/yd^2) offer the most protection, and are durable, so they can be reused for many seasons. A second layer of rowcover can be applied in very cold or windy nights. Rowcovers should be applied to the field during the day prior to cold events, to allow some heat to build up under the cover.

Frost damage can occur under rowcovers without irrigation, especially when the upright flowers are close to the cover. It can be difficult to monitor temperatures underneath rowcover to determine whether irrigation is needed, but newer wireless temperature sensors are well suited to this purpose. If flower temperatures below the rowcover fall to 28˚F, additional protection may be needed. It is possible to combine irrigation and rowcovers, applying water directly over the rowcovers to protect the flowers inside. Applying overhead irrigation over rowcover may be effective during advection freeze events (wind freezes) where rowcover alone may not provide enough protection. Even if irrigation is necessary, less water will be needed to provide the same degree of frost protection under rowcover than if the rowcover were not there.

Chemical Frost Protection Agents

Other approaches to frost protection include the application of chemicals that protect against freeze damage. These approaches have included the use of copper-based sprays that kill ice-nucleating bacteria on the plants, and the use of anti-transpirants, which reduce water loss from plants. Experiments with these materials have not demonstrated consistent efficacy, and they must be applied well in advance of a predicted frost to be effective, so they are not recommended as the sole basis for frost protection.

Warm Temperatures during Fruit Development

Strawberry plants grow best when temperatures range from 60–75˚F, and plants exposed to many hours within this temperature range tend to be vigorous and productive. However, fruit on plants exposed to temperatures greater than 80˚F will become less sweet as some of the sugar will be lost to respiration. The best conditions for sweet fruit are warm days (60–75˚F) and cool nights (45–60˚F). The difference between the average warm temperature and the coolest night temperature between flowering and pink fruit is strongly correlated with sugar and acid content at harvest. Low sugar content is associated with the number of hours developing fruit is exposed to temperatures greater than 80˚F. Certain low tunnel covers under development may be able to reduce the heat load on plants when they are producing fruit.

Hot Temperatures and Evaporative Cooling

Strawberry plants can benefit from sprinkling during hot afternoons to reduce stress. Sprinkling is used routinely in hot, arid climates to maintain fruit size and firmness and to improve overall plant health. Evaporative cooling benefits plants most in hot, dry years; but even in cool summers, the plant canopy and berries can be kept cooler with evaporative cooling. Set automated sprinkler systems to apply water during very hot afternoons (greater than 85˚F) for about 10 minutes every hour. To avoid promting disease, make the last application early enough so that moisture will evaporate before evening.

Further Reading

Remote Monitoring. The University of Vermont Extension: Ag Engineering.

Bootsma, Andrew and D. Murray Brown. *Freeze Protection Methods for Crops.* Ontario Ministry of Agriculture, Food and Rural Affairs, Factsheet #079, 1985.

CHAPTER 6

Water Management

Intensive water management is a key to successful strawberry production. Strawberry tissues contain relatively high percentages of water, with roots and stems ranging from 75–90% water and fruit 88–93% water. Still, root tissues need exposure to oxygen to function properly, and when soils are saturated with water, the water displaces air and starves roots of oxygen. Excess irrigation or rain can also be a problem as it encourages plant and fruit disease and can also dilute fruit flavor and soften berry tissue. Strawberry plants require a consistent supply of water—not just throughout the fruiting period, but also during the entire growing season. Excess or deficient water supply will negatively impact overall plant growth and fruit production.

Water is needed to facilitate fruit enlargement, as fruit expansion is due to individual cells increasing in size, not to further cell division in the undeveloped fruit. Runner rooting and development also requires an adequate and consistent water supply. In the first few weeks of runner establishment, the moisture supply to the mother plant is responsible for the rate and quantity of top growth of the daughter plants. Root growth in the runner plant, which is necessary for plant establishment, can be inhibited if the soil is too dry or too wet.

Irrigation is inexpensive insurance against loss and should be regarded as a requirement for routine production of high-quality crops.

The Need for Irrigation

Water availability is so critical to successful strawberry production that prospective growers should consider this along with soil, markets, and terrain to determine site suitability for strawberry production. Strawberries, like most fruiting crops, should not be planted without an irrigation system in place, or plans for it to be installed immediately after planting. Access to a reliable water source is also necessary. Spring temperatures may warm quickly, pushing plant development that relies on adequate soil moisture to support rapid growth. Prolonged heat and drought, excessive wind, and warmer seasonal temperatures all increase the evapotranspiration rate through soil and plants. The rate at which water is lost varies as the plant canopy changes through the season (figure 6-1).

Water deficit related problems can occur even during years of ideal rainfall. Water stress and resulting yield loss can be prevented with a single irrigation application during critical blossom, fruit set, or berry enlargement periods. The strawberry plant is shallow rooted with up to 90% of its roots located in the top 6 inches of soil. This small rooting area holds little moisture, so the plant is very susceptible to water stress and is a poor competitor with weeds.

Did you know?

In an extensive study of strawberry farms in Ontario, Canada, researchers concluded that:

- Great variability exists between fields on the same farm in their need for irrigation.
- Rainfall can be variable across fields within a farm.
- Most growers do not irrigate soon enough after the last rain event to avoid stressing the plants.
- Most growers do not apply enough water when they irrigate.
- Irrigating strawberries after renovation is critical for yield and stand longevity.

Source: Huffman, Harrow Experiment Station, Ontario.

Separate descriptions of irrigation management for frost protection and evaporative cooling are contained in Chapter 5.

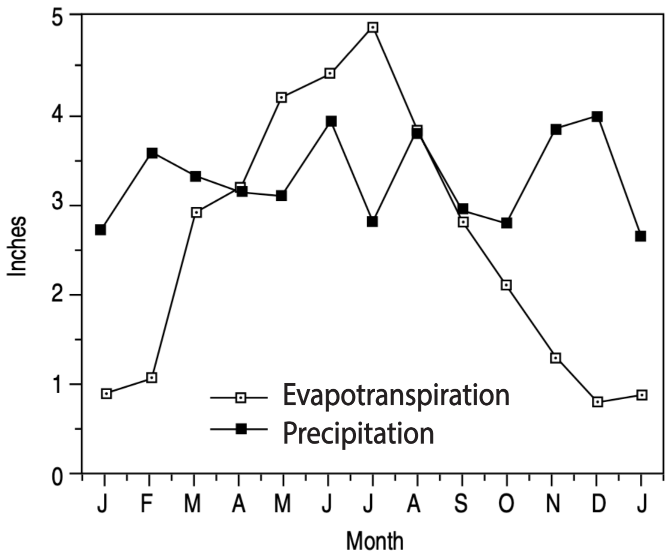


Figure 6-1. Average monthly precipitation and potential evapotranspiration at Aurora, New York, based on 5 years of data.

Overhead vs. Trickle Irrigation

Both overhead and trickle systems are used by strawberry growers for irrigation purposes.

Overhead irrigation applies water to the entire area—wetting leaves, plants, and soil, and eventually roots. Overhead systems may be portable, mobile (travelers), or solid-set (static pipe). Many different types of irrigation sprinklers are available, from those that cover a relatively small area to "cannons," which can irrigate as much as an acre at a time. Overhead systems are frequently used for frost control, but if one uses overhead irrigation for this purpose, monitoring for disease is essential, as water on the foliage and fruit encourage the development of fungal and bacterial diseases, and excess soil moisture can increase risk of soil borne disease. Overhead irrigation systems can also be used to cool plants in the summer when excessive heat can damage fruit.

Trickle ("drip") irrigation offers the advantage of applying water directly to the root zone. **Drip tape** usually refers to a short-term line that is laid on the surface of the soil or buried a couple inches below the soil surface during transplanting. Emitters (holes) in the drip tape can be at a variety of different spacings, and tape can be acquired in different thicknesses. Using drip tape instead of overhead irrigation keeps plant dry and less water is lost to evaporation, allowing irrigation water to be used more efficiently. There is also less risk of disease spread and water damage to fruit because plants are kept dry during flowering and fruiting. If only drip irrigation is used, then some other means of frost protection should be available, such as rowcovers.

When choosing a system, consider efficiency in order to conserve water when possible. Overhead irrigation is inefficient: about 25% is lost directly to evaporation, with additional water lost through system leakage. Irrigation engineers plan for a 40% water loss when determining water capacity needs for an overhead sprinkler system. Thus, if 1 inch of water is needed to replenish soil moisture for the crop and the sprinklers are rated and spaced to apply 1 inch per hour, more than 1 hour would be needed to apply 1 inch of actual water to the soil.

Drip systems are more efficient because they are minimally affected by evaporation. For most on-farm uses, trickle systems are rated at 80–90% efficiency and overhead sprinkler systems at 60–75%. Ongoing maintenance of both types of irrigation systems is necessary to retain best efficiency. Many strawberry growers use both systems at different times to exploit the advantages of each system.

Chemical Injection

Chemigation refers to the process of injecting any agricultural chemical through the drip irrigation system, including fertilizers and pesticides, including biopesticides. Any chemical that is soluble in water can be applied through an irrigation system, but only if chemigation is listed on the product label as an approved method. Some pesticides are not labeled for this application method in strawberries. Nutrients, particularly nitrogen fertilizer, are frequently injected through irrigation systems as this application method is more precise than broadcasting fertilizer over the entire field and is an effective way of applying nutrients directly to plants in a plasticulture system.

Chemigation allows for more uniform and timely applications at about 1/3 the cost of conventional application methods. Precise and well-timed applications help to optimize yield and quality while also reducing the amount of chemicals used. In addition, applicator and environmental exposure to potentially harmful chemicals is reduced, and soil compaction from repeated tractor passes is also limited. Table 6-1 lists the advantages and disadvantages of different chemical injection methods.

> **IMPORTANT:**
>
> Backflow prevention devices are required any time chemicals are injected into irrigation water, especially if municipal water is used.

Water Supply Considerations

While irrigation is extremely important to successful production, the cost of irrigation is largely dependent on an adequate and dependable supply of good-quality water. The water source should be as close as possible to the area to be irrigated to minimize the pumping and supply line cost. Ponds, lakes, streams, springs, groundwater, municipal water, and wastewater are all potential water sources.

The legal right to withdraw water for irrigation must be verified. Water rights in the eastern United States are called riparian, or landowner, rights because anyone is entitled to use any water associated with land ownership. However, a riparian owner's rights are not absolute and are subject to reasonable use interpretations. Some states have water use registration and reporting requirements when a certain number of gallons of water are used, and permits and annual pumping reports may be required. In some western states, water is available only through appropriative rights. Contact your state or provincial agriculture and/or environmental services department for information on water use regulations, especially if you plan to pull a significant quantity and/or the source is shared with neighbors or other farms.

Water sources must be able to provide water as often as it is needed, though this is becoming increasingly difficult for many farms, as many previously reliable water sources are becoming more precarious. In extreme cases of drought, some commercial growers have even needed to buy in or transport water from other locations.

Streams and springs may not provide enough water during the summer when irrigation is needed most. Sometimes municipal water systems allow connections for irrigation purposes. This option may be expensive if water-use prices are high. If the municipality enforces water rationing, it may not permit irrigation during droughts.

Seasonal Water Demand

Seasonal water demand is the total amount required by the planting for the entire growing season. Natural rainfall can contribute to supplying the seasonal water demand, but because it is unpredictable, supplementation from artificial sources is necessary.

Knowing the seasonal water demand is useful for sizing water supply systems where water is stored for irrigation, such as in ponds. In the Northeast and midwestern United States, matted row strawberries require 1–2 inches of water per week, or 25–30 inches per season. The warmer the annual temperatures, the higher the demand. For a 30-day drought period, or a growing season with 15 inches of rainfall, 10–15 inches additional water would be required to meet seasonal demand.

Table 6-1. Comparison of various chemical injection methods.

Injector	Advantages	Disadvantages
Centrifugal Pumps		
Centrifugal Pump Injector	Low cost. Can be adjusted while running.	Calibration depends on system pressure. Cannot accurately control low injection rates.
Positive Displacement Pumps		
Reciprocating Pumps		
Piston pumps	High precision. Linear calibration. Very high pressure. Calibration independent of pressure.	High cost. May need to stop to adjust calibration. Chemical flow not continuous.
Diaphragm pumps	Adjust calibration while injecting. High chemical resistance.	Nonlinear calibration. Calibration depends on system pressure. Medium to high cost. Chemical flow not continuous.
Piston/diaphragm	High precision. Linear calibration. High chemical resistance. Very high pressure. Calibration independent of pressure.	High cost. May need to stop to adjust calibration.
Rotary Pumps		
Gear/lobe pumps	Injection rate can be adjusted when running.	Fluid pumped cannot be abrasive. Injection rate is dependent on system pressure. Continuity of chemical flow depends on number of lobes in a lobe pump.
Miscellaneous Pumps		
Peristaltic pumps	Very low cost. Injection rate can be adjusted while running.	Short tubing life expectancy. Injection rate dependent on system pressure. Low to medium injection pressure.
Pressure Differential Methods		
Suction Line Injection	Very low cost. Injection rate can be adjusted while running.	Permitted only for surface water source and injection of fertilizer. Injection rate depends on main pump operation.
Discharge Line Injection		
Pressurized mixing tanks	Low to medium cost. Easy operation. Total chemical volume control.	Variable chemical concentration. Cannot be calibrated accurately for constant injection rate.
Proportional mixers	Low to medium cost. Calibrate while operating. Injection rates accurately controlled.	Pressure differential required. Volume to be injected is limited by the size of the injector. Frequent refills required.
Venturi Injectors		
Venturi Injector	Low cost. Water powered. Simple to use. Calibrate while operating. No moving parts.	Significant pump pressure required to operate the system. Does not provide a constant parts per million concentration in the irrigation water.
Combination Methods		
Proportional Mixers/Venturi	Greater precision than proportional mixer or venturi alone.	Higher cost than proportional mixer or venturi alone.

Source: Haman, et al., *Chemical Injection Methods for Irrigation,* Florida Cooperative Extension Service, 1990.

Growers should allocate from 3–13 acre-inches of water for each acre irrigated during the season. An **acre-inch** is a unit of volume equal to 1 inch of water depth over an entire acre, and is equivalent to 27,154 gallons of water.

Because overhead sprinkler irrigation systems are 60–75% efficient, the rule of thumb is to store 40,000 gallons of water for every one-acre-inch application. For example, a 5 inch seasonal demand would require 200,000 gallons per acre (5 inches x 40,000 gallons per acre-inch) if irrigated with an overhead sprinkler system. To irrigate a 20-acre parcel, a total of 4 million gallons (200,000 gallons per acre x 20 acres) should be available in storage. To store this water, a grower would have to have a 200 x 200 foot pond that can store water to a depth of 13.4 feet (1 cubic foot = 7.48 gallons) or have a smaller pond with a rapid recharge rate.

Peak Evapotranspiration Rate (Daily Peak Use Rate)

At some time during the growing season, environmental conditions and crop characteristics will demand peak water-use, or metric evapotranspiration rates. The **peak evapotranspiration (ET) rate** is another useful metric for sizing water supply systems (flowing springs, streams, wells, or municipal systems). Both the water supply and the irrigation system must be capable of supplying water at the peak rate. Irrigation schedules based on the daily peak use ensure that enough water is applied when needed. The daily water demand is highest when irrigating for frost protection or when replacing the 1¼ iches of water that can be lost each day during the summer due to evapotranspiration.

Peak ET rates are the highest in July and August and for most sites in the northeastern and midwestern U.S., average peak use in those months ranges from 0.19–0.24 inches per day. Since these rates represent long-term and monthly averages, demand during any single day could be another 25% higher, especially under hot, windy conditions. For example, if the potential peak ET rate averages 0.22 inches per day, you will need about 5,970 gallons (27,154 gallons per acre-inch x 0.22 acre-inch) to irrigate 1 acre to a depth of 0.22 inches during a 24-hour period. This will require an irrigation system that can supply about 5 gallons per minute (gpm) to each acre irrigated (5,970 gallons ÷ 1,440 minutes per day).

If these values are increased 25% to account for higher single daily peak uses in the months of July and August, then the average peak use rate becomes 0.28 inches per day with a requirement of 5.3 gallons per minute per day per acre [(27,154 gallons per acre-inch x 0.28 acre-inch) ÷ 1,440 minutes per day]. Thus, a spring, stream, well, or municipal water source would have to supply 4–5 gpm continuously for each acre irrigated to meet the peak demand in the summer months.

Round-the-clock irrigation is not always possible or desirable, so growers must make the numerical adjustments for the number of hours they plan to irrigate. For example, to irrigate for only 10 hours a day with a sprinkler system operating at 75% efficiency, then the water supply must be capable of delivering approximately 16 gallons per minute per acre to meet the daily demand discussed in the previous paragraph.

Water Source Capacity

The required amount of water needed by the plant will help determine application rate. The source of the water must have enough capacity to fill that requirement throughout the production season.

Flow rate and pressure are also critical to the design of the irrigation system as this information will help to determine how many plants you can water at any one time, and how many zones you may require. The application rate is defined by the needs of the plant and the type of soil and site situation. A newly planted strawberry plant on heavier ground will have a smaller irrigation application rate requirement than will a fruiting matted row on sandy soil. Flow rate is usually measured in gallons per minute. To measure the rate of water flow, use a 5-gallon bucket and record how long it takes to fill it from an outlet at the water source. For example, if it takes 45 seconds to fill a 5-gallon bucket, divide 60 seconds by 45 seconds and multiply by 5.

For example:

$$\text{Flow rate} = \frac{60 \text{ seconds}}{1 \text{ minute}} \times \frac{5 \text{ gallons}}{45 \text{ seconds}} \quad \frac{6.67 \text{ gallons}}{1 \text{ minute}}$$

Gallons per hour = 60 minutes x 6.67 gallons per minute = 400 gallons

Pressure is determined using a pressure gauge on pump systems and is measured in pounds per square inch (psi). Pressure decreases over distance traveled regardless of the type of tubing materials. Contrary to what many people think, pressure will also decrease as the diameter of the tubing gets smaller. This is due to the friction of movement: the smaller the diameter, the more friction for the volume of water moving through the tube. Interestingly, the speed of the water flowing through a smaller hose will increase. If you're interested in this phenomenon, look up Bernoulli's principle and the Venturi effect.

In addition to the inherent pressure loss of the system, lost pressure from leaking emitters or leaks in the lines is common. Regular inspection of the system can help prevent leaks. Irrigation suppliers can provide information about the capabilities of equipment in terms of gallons per minute capacity and psi lost over 100 feet, along with the ease of repairing leaks while the system is in use.

Water Quality

Water quality should be assessed when choosing a water source. Water quality includes its physical, chemical, and biological constituents. Water quality from surface water sources has normal seasonal variation but can often become an issue during drought.

Physical constituents refer to sand, silt, or other suspended materials in water. While the physical constituents are usually not damaging to fruit crops, they can damage or clog the irrigation system. A high sand content, for example, damages pumps and sprinklers, and suspended materials can clog trickle systems. Surface water sources, such as ponds and rivers, usually contain more particles and should be evaluated carefully, especially if trickle irrigation is being considered. Filtering or frequent backflushing of screens is required when using pond water for trickle irrigation (photo 6-1). Screen and disc filters clog if the water contains algae or organic materials. A media (sand) filter works best for surface water because it has more depth for trapping particles and the media is lifted during backwash to flush the debris out.

Photo 6-1. Irrigation filter (D. Handley).

Chemical constituents of water refer to pH, dissolved material, proportions of dissolved ions, and any organic compounds such as oil. Although generally not a problem, organic solvents or lubricants in the water can damage plants. If water pH is high (7.0 or above), lower it with sulfuric acid to prevent nutritional problems in the field. Furthermore, certain pesticides can be deactivated by high-pH water, so it is important to be aware of the water pH.

Biological constituents such as bacteria and algae are often present in surface water. They are usually not harmful to fruit crops and can be controlled under most circumstances, but they can affect irrigation system performance. Water contaminated with sewage or animal manure should not be used to irrigate strawberries. See Food Safety Considerations for Production Water.

Food Safety Considerations for Production Water

When planning water usage for strawberry production, it is important to consider the microbial quality of water sources. *Escherichia coli* (*E. coli*), *Salmonella*, *Campylobacter*, and *Listeria* are examples of important pathogens that can be spread through irrigation water, causing foodborne illness. In general, municipal water is considered to be of lowest risk for agricultural use, since it is tested frequently to meet potable drinking water standards by municipalities. Ground water is considered medium risk; water is filtered through soil and vegetation that lower pathogen loads. The riskiest source of water from a food safety standpoint is surface water, which is open to the environment.

The only way to determine the microbial quality of a water source is to adopt a water testing schedule during the production season. Ground water should be tested at least once per growing season, and surface water 5 times. Generic *E. coli* is an excellent indicator organism for the presence of fecal material and pathogens in the water, therefore, tests quantifying generic *E. coli* are recommended. Ponds, streams, rivers, and lakes often experience high *E. coli* levels during the summer due to increased temperatures, wildlife activity, and recreational use. Do not use water sources known to be contaminated with sewage or livestock for strawberry production.

To minimize risk from surface water use, avoid using overhead irrigation immediately prior to harvest. Maximize the time between irrigation and harvest to allow any pathogens on the plant surfaces to die off during exposure to sunlight and wind. Additionally, use drip irrigation whenever possible to avoid wetting the flowers and fruit.

Lastly, inspect the water source and distribution system for food safety risks. Exclude or deter wildlife and livestock from water sources, and do not permit swimming in on-farm irrigation ponds. Inspect well heads and recharge areas annually to make sure they are intact.

Planning an Irrigation System

For initial implementation or large systems, it may be helpful to consult an irrigation specialist before planting. Be sure to communicate specific insight and knowledge about the site, as the more information that is provided, the better the design will be. Information required for an irrigation system design might include:

1. An aerial photograph of the entire farm.

2. A topographic map showing 10–20 foot variations.

3. A detailed sketch of the fields and management data. Specifically, an irrigation designer will need:

- Field diagrams with dimensions and location relative to other fields. Water location and power sources should be noted.
- Approximate elevation variation in the field(s)
- Type of soil and soil texture
- Plant type and details that relate to timing and amount of water required for that type of plant
- Length of rows
- Row direction
- Number of rows per field (trickle)
- Distance between rows (trickle)
- Spacing of plants in the row (trickle)

4. Water supply information for pond, spring, stream, well or municipal sources.

- For ponds: the source of pond water (springs or streams), the approximate size and depth, water-holding ability through the summer, approximate recharge rate, and a description of the cleanliness (weed growth, algae on the surface, silt buildup). Water test results may be helpful.

• For streams: communicate the seasonal variation in water availability, the approximate flow rate in gallons per minute, and a description of the water cleanliness during the summer season. To test for cleanliness, take a water sample and allow it to settle before describing.

• For wells: the capacity (gallons per minute at zero pressure), size (diameter) of the well casing and the water pipe inside, depth, standing water level, and well identification number. Have the water tested for iron and pH and note whether there is sand or silt in the pumped water.

5. Existing equipment information, including pump specifications.

6. Electrical power availability. If possible, note the voltage and phase available, the distance of the electricity from the pump site, and the power company's address and phone number.

7. Include future irrigation needs as known.

A well-designed irrigation system will match water supply capacity with crop water requirements and how the water will be delivered, while considering other design factors.

Irrigation System Components

Sprinkler and trickle systems have some common components, such as the pumping unit, control head, mainline and submain pipes, and laterals. The water distribution hardware for both systems is similar (figure 6-2). Differences between systems are just the physical characteristics and the equipment that ultimately applies the water, either sprinklers or emitters.

Pumping Unit

The pumping unit, which consists of a pump coupled to a power source, draws water from the supply source and pressurizes it for delivery through the irrigation system. A centrifugal pump or a submersible or deep well turbine pump may be used. Normally, a centrifugal pump cannot be placed more than 20 feet above the water line. Pumps are available in a wide range of flow capacities and delivery pressures. Selecting the correct style of pump and the proper size will depend on site characteristics and the final irrigation system layout.

Pump size depends on the discharge or amount of water to be delivered at a given time (that is, the number of sprinklers being operated simultaneously multiplied by the discharge rate of sprinklers), and the head pressure required to lift the water and operate the sprinklers or trickle emitters. Since sprinklers usually have higher discharge and pressure requirements, pumps for sprinkler systems are generally larger than those for trickle systems. This is one reason why trickle systems are more energy-efficient than sprinkler systems.

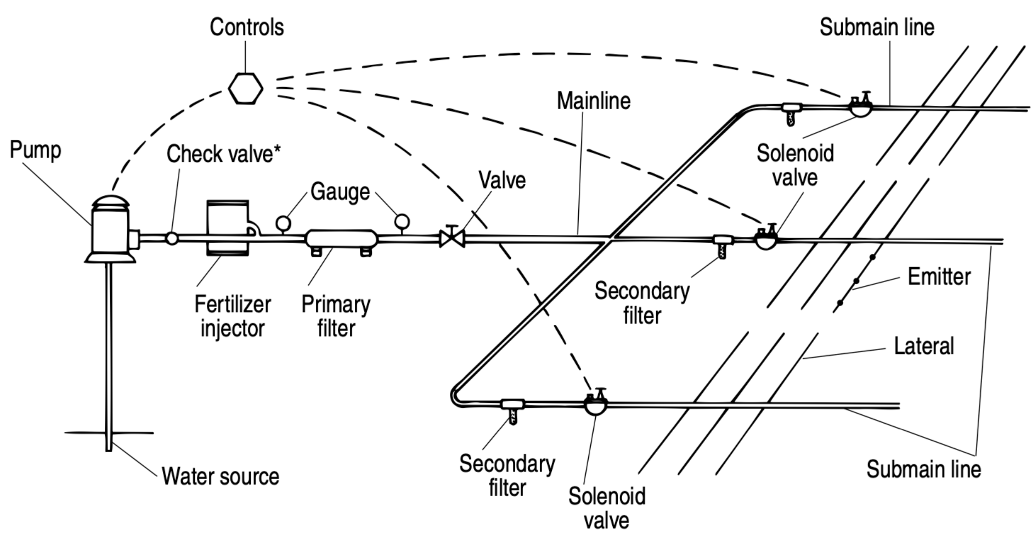


Figure 6-2. Irrigation system components. A backflow preventer or vacuum breaker is required in some locations.

Although the pumping units must meet certain hydraulic requirements, several options are usually available to meet site requirements and preferences. When growers tie into municipal or household systems, where water is already pressurized, a pumping unit is unnecessary. The primary concern is that the supply (volume and flow rate) is large enough.

Pumping and pressurizing water can be expensive (table 6-2). Pumping one acre-foot of water from a well 100 feet deep with a pump running at 70% efficiency costs about $130 (at $0.13 per kilowatt hour). The energy cost to pressurize surface water to 43 psi is the same as lifting the same volume of water 100 feet.

Table 6-2. Cost to pump one acre-foot (325,850 gallons) of water 1 foot in elevation, assuming $0.13 per kilowatt-hour. Pumps generally run at 60–80% efficiency,

Pump Efficiency	Energy Requirement (kilowatt hours)	Cost
100	1.02	$0.134
75	1.37	$0.178
60	1.71	$0.222
50	2.05	$0.267
40	2.56	$0.333

Control Head

The control head is the combination of items that control, measure, or treat the water. Control heads can range from simple, manually operated heads with a single valve to quite sophisticated heads with automatic controllers and sensors, water meters, pressure regulators, filters, and nutrient or chemical injection equipment. Control heads for trickle systems are often more complex because of the necessary water filtration equipment.

Automated equipment can be adapted to some systems to measure soil moisture, start the irrigation system, and send water to the appropriate areas. The more complex and automated the control head and irrigation system, the greater the initial capital investment.

Mainline and Submain Pipes

Mainline and submain pipes deliver water from the pump and control head to the laterals. These pipes are usually classified as permanent, rigid and portable, or flexible and portable. Submain pipes are not always necessary.

Permanent piping is usually made of galvanized steel or plastic (either rigid PVC or polyethylene). This piping is installed below ground, with the exception of steel pipe, which can be installed above ground. For perennial crops such as blueberries, permanent buried main lines with hydrants spaced throughout the field offer several advantages, but they require high initial investment.

Rigid and portable (solid-set) piping is usually made of lightweight aluminum equipped with quick coupler fittings. Although moving pipe is labor-intensive, portable piping systems offer flexibility and provide irrigation at a lower initial cost.

Flexible and portable pipe refers to conduits made with lightweight, durable rubber or synthetic compounds. These pipes are generally used with self-propelled sprinklers but can be used to run water from a water source to a nearby field.

Although friction losses decrease per unit length from steel to aluminum to plastic pipe, proper pipe diameter is a more important factor for flow velocity. Pipe size is determined according to the discharge requirement, the allowable flow velocity within the pipe, and the trade-off between the tolerable friction loss and the total time of system operation in which that loss must be overcome. Since the total discharge requirements for sprinkler systems are higher than those for trickle systems, pipe sizes are often larger with sprinkler systems.

Pipe type (its material and whether it is permanent or portable) is generally not a major factor in achieving desired flow characteristics. Therefore, equipment selection depends mainly on the grower's preference and a trade-off between equipment and labor costs.

Lateral Pipes

Lateral pipes deliver water from the mainline or submain lines to the sprinklers or trickle emitters. They are of the same 3 general types as the mainline pipes but are usually smaller. Lateral pipe sizes are designed to minimize pressure losses so that sprinkler or emitter discharge at the far end of the lateral stays within 10% of the sprinkler or emitter discharge near the mainline to provide uniform water application. Pressure is usually lower in trickle laterals than in overhead laterals. Some trickle system laterals combine the functions of a lateral and an emitter; these include porous pipe, perforated pipe, and multi-chamber tubes.

Components Specific to Trickle Irrigation Systems

Compared to sprinkler nozzle sizes, trickle system emitters (which are just perforations in the drip line) have very small openings, usually pinhole size. Different emitters have different internal flow characteristics that determine how sensitive they are to pressure changes and particles in the water. A 150–200-mesh screen is normally required for water filtration.

Some emitters have larger orifices, are self-cleaning, or can be taken apart and cleaned. Periodic chlorine injections can keep systems free of algae, bacterial slime, and iron precipitates. Chlorine treatment (resulting in 1–2 parts per million [ppm] residual chlorine at the emitter) should occur up-stream from the filter in order to remove precipitated iron and microorganisms. This may require 5–10 ppm chlorine at the injector, especially if there are high levels of iron or microorganisms in the water. Swimming pool test kits can be used to calibrate the chlorine levels. If water pH is above 7.5, chlorine will not be effective. Separate acid injections, along with periodic flushing of the system, also help remove mineral buildup.

Emitters normally operate at pressures of 5–40 psi, with flow rates of 0.5–1.5 gallons per hour. Emitter spacing depends on the discharge rate and soil type because most of the water distribution is through the soil. The low-pressure requirements of emitters result in more sensitivity to pressure losses along a lateral line or an elevation gradient. Pressure-compensating emitters may be necessary to achieve uniform water application on rolling terrain. Since the pressure and discharge requirements of emitters are usually smaller, the annual operating costs of trickle systems tend to be lower than those for sprinkler systems. Trickle irrigation systems should be sized for the mature planting.

Components Specific to Overhead Irrigation Systems

The basic types of sprinklers include rotating sprinklers, stationary spray-type nozzles, and perforated pipe. Rotating sprinklers, such as the slowly rotating impact-driven sprinkler, are most common (photo 6-2). Fixed spray nozzles are becoming more popular, although they are most widely used in landscaping. Perforated pipe is the simplest sprinkler, consisting of a pipe with numerous holes through which the water sprays.

Photo 6-2. Standard overhead irrigation nozzle and riser for strawberries (D. Handley).

Rotating impact sprinklers come in many sizes and variations to meet various design conditions. Some micro-sprinklers operate at pressures as low as 10 psi, while the large gun types require pressures exceeding 80 psi. Sprinkler discharge ranges from a few gallons of water per minute to 1,000 gallons per minute for a big gun. Wetted diameters can range from only a few feet to several hundred feet. When irrigating new plantings, avoid big guns with high pressures.

When selecting an irrigation system solely to provide water to the plants, use a high discharge rate with large droplets to minimize evaporative loss and the time that foliage is wetted, but do not use such a high rate as to cause puddling in the field.

Pressure, discharge rate, and wetting diameter are the most significant characteristics of a sprinkler; but nozzle size, jet angle, wind speed and direction, sprinkler overlap, and sprinkler rotation speed are also important. These characteristics determine water application rates, sprinkler spacings, and water droplet sizes. For uniform water application, sprinklers are generally spaced so that 50–60% of their wetted areas overlap. Annual operating costs of irrigation increase with increasing pressure and discharge requirements. Large gun-type sprinklers will require up to twice as much fuel or electrical energy as smaller sprinklers to apply equal amounts of water.

Equipment Use and Maintenance

The appropriate use and maintenance of irrigation equipment, both in season and during storage, will increase its life and reduce operating and maintenance costs. An irrigation equipment dealer should provide an owner's manual and guidelines for operating and caring for the equipment.

The pumping unit and control head will require the most maintenance in terms of lubrication, cleaning, and protection from dirt, moisture, freezing, and animals. Leaking pump seals and pipe gaskets should be replaced as necessary. Sprinkler nozzles that are worn more than 1⁄16 inch larger than specified, or emitters that are clogged, should be replaced. Mains and laterals, particularly in trickle systems, should be flushed periodically to remove buildup of precipitates and sediment. Equipment used in freezing weather must be properly lubricated and should be self-draining. The careful use and continued maintenance of irrigation equipment should ensure many years of trouble-free performance.

Scheduling and Running Irrigation

Once an irrigation system is in place, the major decisions are when to irrigate, how much water to apply, and how to use and maintain the equipment. Always irrigate when drying will be rapid—avoid irrigating at night unless doing frost protection. Prolonged moisture on leaves and fruit encourages fungal development. Avoid windy conditions, as wind increases water loss due to evaporation.

Crop rooting depth, canopy development, fruiting habits, and nutrition and water requirements largely determine the irrigation schedule. Soil infiltration and water-holding characteristics (tables 6-3, 6-4, and 6-5) help determine the rate and duration of water application and affect the soil's ability to make water available to plants. Actual water use will vary daily throughout the season, so develop a method to make sure the crop has an appropriate amount of water available. Never apply water faster than the soil can absorb it, unless irrigating for frost protection.

Table 6-3. Infiltration rates of overhead irrigation for various soil types

Soil Texture	Infiltration Rate (inches/hour)
Coarse sand	0.75–1.00
Fine sand	0.50–0.75
Fine sandy loam	0.35–0.50
Loam or silt loam	0.25–0.40
Clay loam	0.10–0.30

Note: Do not apply water faster than the soil can absorb it, unless irrigating for frost protection.

Table 6-4. Maximum irrigation period (hours) with trickle irrigation for various soil textures, assuming 50% moisture capacity at the beginning of the cycle.

Flow Rate (gal/hr/100 ft)	Soil Texture				
	Loamy Sand	Sand	Clay Loam	Silt Loam	Loam
12	5.0	8.0	11.5	11.5	17.5
18	3.5	5.0	7.5	10.5	11.5
24	2.5	4.0	5.5	8.0	8.5
30	2.0	3.0	4.5	6.5	7.0
36	1.5	2.5	4.0	5.0	6.0
42	1.5	2.0	3.0	4.5	5.0
48	1.5	2.0	3.0	4.0	4.5

Several methods are used to determine whether or not to irrigate, some being more reliable than others. When plants show visible signs of water deficit, such as wilting, plant growth has already been severely affected. Irrigation at this point may save the crop, but production will still suffer.

Table 6-5. Water-holding capacity of various soil types.

Soil Type	Inches Water/ Inch Soil
Sand	0.02–0.06
Fine sand	0.04–0.09
Loamy sand	0.06–0.12
Sandy loam	0.11–0.15
Loam	0.17–0.23
Silty clay loam	0.14–0.21
Clay	0.13–0.18

Feel Method

While this method is successfully used by some experienced growers, the common mistake of not sampling the soil around the root tips and focusing only on surface soil makes this "feel" method less reliable than some alternatives. The feel method uses the soil's appearance after being squeezed by hand to estimate water content. Charts are available to describe how different soils should look and feel at different moisture contents. To avoid the problem of only sampling the surface soil, use a probe to sample soil in the crop root zone.

Water Budget Method

The water budget method is an accounting process of daily water use and rainfall inputs. Plant water use is estimated daily based on crop development and climate conditions, and is compared to the soil's water-holding capacity. Often, pan evaporation is used to keep track of water losses. An evaporation pan is literally a pan with a gauge in it to determine how much water has evaporated, which is correlated with plant evapotranspiration.

Assume that the rooting depth of strawberries is 8 inches on a sandy loam, high-organic-matter soil. After a soaking rain or after irrigation, the soil should hold about 1.2 inches of water (8 x 0.15 inches [from table 6-5]). Irrigation should begin when available water is depleted by 50%, or 0.6 inches in this example. If evapotranspiration removes about 0.22 inches of water per day from the soil, then after 3 days 50% of the available water is depleted, and water is required. With the water budget method, moisture loss is monitored and continuously calculated, and water is replaced based on the calculations.

With experience, this method can be quite reliable. Computer software programs using this budget method are available and can be adapted to site conditions. Computers can also be used to automate irrigation. Current resources include:

- Wisconsin Irrigation Scheduler
- Michigan Irrigation Scheduler
- Arkansas Irrigation Scheduler
- Kansas Irrigation Scheduler
- NDSU 'Checkbook' Scheduler
- Arizona Irrigation Scheduler
- USDA CropFlex
- Woodruff Irrigation Model

Guttation Method

Strawberry plants exhibit a phenomenon called guttation, which is the exudation of water droplets from small pores at the tips of the younger leaves (photo 6-3). Guttation droplets are seen only in the early morning in the driest area of a given field; growers need to examine the tips of the youngest leaves coming out from the crown. Placing a bucket over the area to be examined the evening before will eliminate any evaporative loss of guttated water from wind. If water droplets are not being exuded, it's time to irrigate. This system is appealing as it allows the plant to tell the grower when the water supply in the soil is dwindling, but it's not frequently used for irrigation scheduling.

Photo 6-3. Guttation in a strawberry leaf (K. Orde).

Other Tools for Measuring Soil Water

Many instruments are available that can help growers schedule irrigation. Evaporation pans, atmometers, infrared thermometers, pressure bombs, and porometers monitor evaporative demand, plant stress, or leaf moisture status. Tensiometers, gypsum or ceramic electrical resistance blocks, conductivity probes, matric potential (heat-dissipating) sensors, neutron probes, and time domain reflectometry (TDR) probes are used to monitor soil moisture. Some of these tools, such as evaporation pans, atmometers, tensiometers, and gypsum blocks, are relatively inexpensive and easy to use. Others are more expensive and are used mainly for research. All of them require constant monitoring, maintenance, and calibration to be reliable for scheduling irrigation.

A **tensiometer** is a simple, inexpensive, and underutilized tool for measuring soil moisture status (figure 6-3; photo 6-4). The ceramic tip of the tensiometer should be placed in the rooting zone of the strawberry plant, approximately 6inches deep. When the reading reaches a critical level, irrigation is required. This critical level depends on soil type. Soil moisture should not be depleted below 50% of the soil's capacity. Irrigation should be started when the tensiometer reading reaches this level, about 20–40 centibars (cbars) in sandy soils, 40–60 cbars in loamy soils, and 50–80 cbars in clay soils.

Tensiometers work well in sandier soils but may require more service. When the soil dries out too much, there is so much pressure in the tensiometer that the water column pulls apart, and air enters where a vacuum once was. Servicing involves refilling the tensiometer with water and pumping back out all of the air, so the column is again completely filled with water.

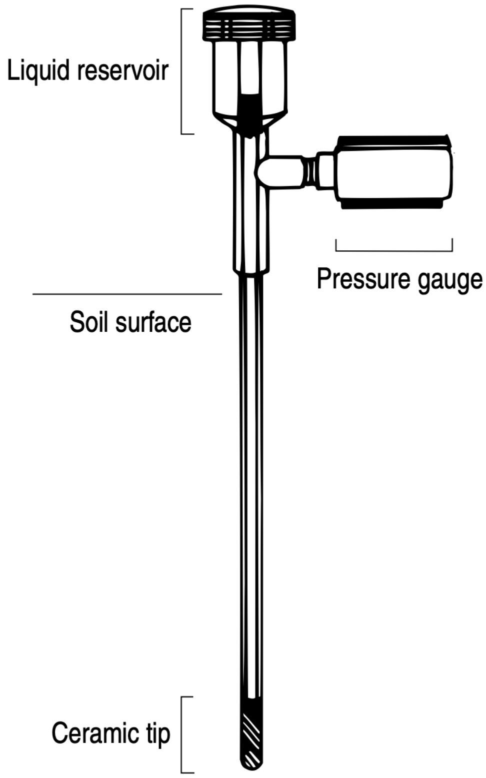


Figure 6-3. The components of a tensiometer.

Photo 6-4. A tensiometer is an easy-to-use low tech tool for monitoring soil moisture levels (D. Handley).

Gypsum blocks are also inexpensive, simple to use, and can reflect moisture more accurately in drier soils than tensiometers. Practically speaking, they don't offer much advantage, since plants should be watered before soil moisture falls below 50% of capacity. The gypsum block contains 2 electrodes cast in a small block of gypsum. The gypsum protects the electrodes from corrosion and confines the electrical path to within the block. A hand-held battery-operated resistance meter is connected to the wires to indicate the electrical resistance. The more water there is in the soil (and in the gypsum block), the more the current will flow within the gypsum block between positive and negative charges.

Some instruments have been developed for automated monitoring of water requirements and, when integrated with the appropriate irrigation system, can automate the entire irrigation process.

Further Reading

Goulart, B. L., P. H. Heinemann, T. Stombaugh, K. Demchak, and C. T. Morrow. 1993. "Automated Irrigation for Strawberry Production." Acta Horticulturae 348:196–206.

Haman, D. Z., A. G. Smajstria, and F. S. Zazueta. Chemical Injection Methods for Irrigation. Circular 864. Florida Cooperative Extension Service, 1990. Publications Distribution Center, AFAS Building 664, University of Florida, Gainesville, Florida 32611.

Ross, D. S. Chemical Proportioners for Irrigation Systems. Bulletin 179. 1990. University of Maryland Cooperative Extension Service, Symons Hall, College Park, Maryland 20742.

Ross, D. S. and H. L. Brodie. Soil Moisture Sensors for Irrigation Management. Bulletin 312. 1985. University of Maryland Cooperative Extension Service, Symons Hall, College Park, Maryland 20742.

CHAPTER 7

Soil and Nutrient Management

Managing nutrition is important to the overall management of a strawberry planting. Each farm is different, and each needs a plan that considers the farm's soil conditions, practices, and goals. Many factors influence nutrient uptake and availability. For example, pH, moisture, organic matter content, clay content, and mineral composition of the soil all strongly influence nutrient availability. Management practices such as tillage, irrigation, herbicide use, and fertilization also affect the plant's ability to take up nutrients. Finally, weather plays a role: conditions that reduce transpiration (e.g., dry and cold) may cause temporary nutrient deficiencies. Since all of these factors interact to affect nutrient uptake and since these factors differ from farm to farm, it is difficult to provide specific recommendations. However, an understanding of certain principles will allow a grower to better develop a nutrient management plan for their farm.

Soil Components

The biological, chemical, and physical characteristics of a soil determine how well that soil sustains good plant growth. Soils with nearly identical soil tests can produce crops with very different yields depending on the biological activity in the soil and/or how compacted that soil might be. A soil management plan should seek to improve the physical, biological, and chemical properties of the soil.

Physical Properties

Soil is the substrate in which the roots grow, anchoring the plant. It is also the medium that provides nutrients and water to the plant. The 4 major components of soil are minerals, organic matter, water, and air (figure 7-1). These 4 components must be in balance to achieve optimal plant growth. For example, excessive water can reduce the oxygen content of the soil and cause roots to die. Insufficient water causes plants to wilt and inhibits nutrient uptake.

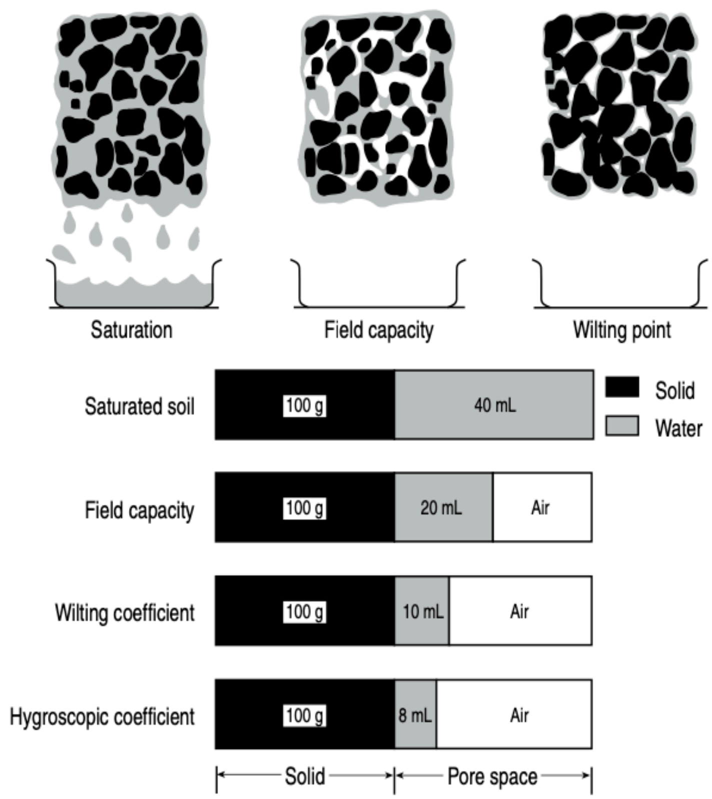


Figure 7-1. Components of soil.

A decline in soil physical properties is often associated with excessive or improperly timed tillage. Tillage can lead to compaction if it is done too frequently or under wet conditions. Compacted soils are difficult for rooting and hold less water and air than uncompacted soils. Incorporating a cover crop or mulch is a good use of tillage equipment. Repeated deep tillage for weed control is not a good practice.

Incorporating organic matter usually improves soil physical properties as it helps the soil form aggregates and enhances internal drainage. Installing drainage also helps improve soil physical properties and can promote good plant growth. In soils with a high sodium content, applications of calcium sulfate (gypsum) will help with flocculation, a process of bonding between particles to form larger soil aggregates, increasing internal drainage. and internal drainage. This is usually not a problem in the East unless salt has accumulated from fertigation over time. Some soils (e.g., heavy clays) are difficult to improve and should be avoided.

Biological Properties

Most bacteria and fungi in the soil are either benign or helpful to plants. Fungi and bacteria are the base of the food chain and they derive most of their energy from organic matter. Therefore, increasing soil organic matter content almost always improves soil health as it enables these soil microorganisms to compete better with any pathogens that might be present. Soil microorganisms are also critical for decomposition of organic matter and recycling of nutrients.

There are several opportunities for perennial strawberry growers to increase soil organic matter. The best opportunity is to incorporate cover crops or manure prior to planting. A second opportunity is to use straw mulch between rows to suppress weeds and reduce soil-fruit contact. During renovation, this straw can be incorporated between rows before straw is applied again the following winter.

Rotating crops will reduce the accumulation of pests in a particular site, leading to improved soil health. The most useful species are those not closely related to strawberries such as grasses/grains (see Chapter 2 for suggestions). Excessive chemical use will decrease soil health. This includes both chemical fertilizers and pesticides. Excessive tillage oxidizes organic matter and increases compaction. Avoid overusing tillage equipment, particularly rototillers.

Mineral/Chemical Properties

The composition and size of the mineral fraction of soil has a large influence on nutrient availability. Nutrient availability increases when soil particles are small. Nutrients tend to be more available in loamy soil than in sand, given the same overall chemical composition. Some minerals are insoluble in water, so the associated nutrients may be relatively unavailable even when they are present in large quantities. Mineral composition also affects the release rate of nutrients; for example, certain clays have a lattice structure that traps ions between layers, rendering them unavailable. A soil high in phosphates or high in pH can also reduce the availability of certain nutrients, such as iron and zinc. Because the chemistry governing nutrient availability in soil is complex, predictions about crop response to soil type or fertilizer addition are imprecise.

Organic matter is another major component of soil and consists of decomposing plant material, animal wastes, and microorganisms. Organic matter is a source of nitrogen, phosphorus, and sulfur, and increases the availability of positively charged ions, such as calcium, magnesium, and potassium. Organic matter constituents tend to have a negative charge that holds onto positive ions, increasing their availability to plants. Soils that are high in organic matter content also have a large buffering capacity, are resistant to changes in pH, and tend to have a high water-holding capacity.

Basic Principles of Soil Nutrition

Often soil contains sufficient nutrients for plant growth, but they may be in a form that is unavailable to the plant. For example, a soil may contain 25,000 parts per million (ppm) potassium, but the amount available to the plant may be just 500 ppm. Many of the factors listed previously influence the conversion of mineral elements from unavailable forms to available forms. Soil tests attempt to estimate the amount of plant-available nutrients, not the total amount in the soil.

Nutrients are available to the plant as individual ions with a positive, negative or neutral charge (Table 7-1). The behavior of nutrients in the soil is influenced significantly by this charge. For example, ammonium (NH_4) tends to be retained by adsorption to negatively charged clays and organic matter, whereas nitrate (NO_3^-) is more readily leached. When ammonium is taken into a root, a proton (H^+) is excreted to maintain a neutral charge balance. The additional hydrogen ions that result from ammonium fertilization decrease the soil pH and affect the availability of other nutrients. Boron has a neutral charge so is not held tightly in the soil.

Soil pH is the most important factor affecting the availability and uptake of plant nutrients, assuming adequate water is available. Some nutrients become more available at a low pH, others at a high pH, and others between pH extremes (figure 7-2). At a soil pH of 6.0–6.5, all essential nutrients are potentially available to the plant, so this is the recommended target for pH adjustment in most locations. However, in cases where certain micronutrients are present at high or low levels, the optimal soil pH may be slightly higher or lower than 6.0–6.5.

Table 7-1. Ionic forms of plant-available nutrients supplied by the soil.

Element	Cations	Anions	Neutral
Nitrogen	NH_4^+	NO_3^-	
Calcium	Ca^{2+}		
Magnesium	Mg^{2+}		
Potassium	K^+		
Phosphorus		HPO_4^{2-} $H_2PO_4^-$	
Sulfur		SO_4^{2-}	
Copper	Cu^{2+}		
Iron	Fe^{2+}, Fe^{3+}		
Manganese	Mn^{2+}		
Zinc	Zn^{2+}		
Boron			H_3BO_3
Molybdenum		MoO_4^{2-}	
Chlorine		Cl^-	

If a particular nutrient is limiting plant growth, then the plant will respond positively to incremental increases in the limiting nutrient. However, if a nutrient is not limiting, then increasing its availability will not increase growth of the plant. In fact, too much of a particular nutrient can be toxic or, more frequently, interfere with the uptake of another essential nutrient with similar chemical properties. At least 13 nutrients are essential to plant growth. Although nitrogen (N), potassium (K), phosphorus (P), calcium (Ca), magnesium (Mg), and sulfur (S) are the soil nutrients required in the greatest amounts, micronutrients such as molybdenum (Mo) are equally important, even though Mo is required at levels about 100,000 times less than N, P or K.

Providing additional nutrients will not always benefit the plant. If the level of a particular nutrient is low, adding a small amount often results in a growth flush. This tends to dilute the concentration of the nutrients in plant tissues, although the total amount in the plant is greater. For this reason, it is not unusual to see certain foliar nutrient levels fall after fertilization.

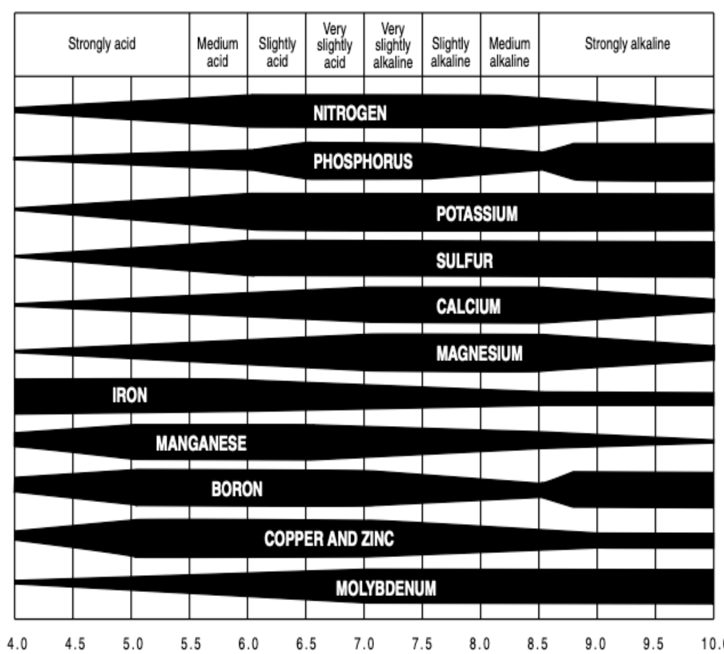


Figure 7-2. Nutrient availability as affected by soil pH.

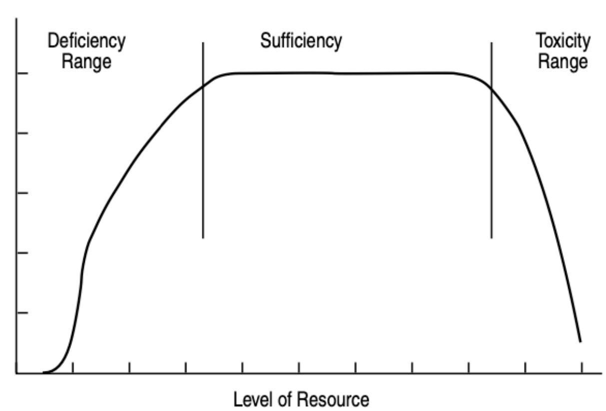


Figure 7-3. Response of a plant to increasing levels of a resource.

Preventing and Diagnosing Nutrient Problems

Visual Diagnosis

An obvious method for determining whether plants are receiving adequate nutrients is to look for symptoms such as pale foliage, poor growth, misshapen fruit, and discolored plant tissue. Often particular combinations of symptoms are associated with specific nutrients. The disadvantage of relying on visual diagnoses is that by the time symptoms appear, performance is already compromised. Also, it is rare that only a single nutrient is deficient. For example, if the soil pH is too high, then iron (Fe), manganese (Mn), and zinc (Zn) become unavailable almost simultaneously. Multiple deficiencies make visual diagnoses difficult. Finally, symptoms of toxicity can sometimes resemble symptoms of deficiency. Basing fertilizer recommendations on visual symptoms alone is risky.

Soil Tests

Soil tests have been used for many years to estimate the amounts of nutrients available to plants. Once these numbers are known, a recommendation is made with the assumption that plant performance is related to nutrient availability. Using a soil test to assess nutritional status is much better than relying on a visual diagnosis of plant symptoms, but the test must be done correctly to ensure valid results.

Take soil samples for testing from the top 8 inches of soil. This is where most of the strawberry roots will grow. Collect samples from 10–12 locations throughout the field (refer to figure 2-1) and mix them together in a bucket. Remove about one pint of the bulked soil for analysis. More than one test is required when the soil changes within the field. No more than 10 acres should be included in any one sample.

Soil should be tested the year prior to planting. With the exception of N, sufficient fertilizer and lime can be applied and incorporated before planting strawberries to meet nutritional needs over the life of the planting. Soilless substrate culture, in contrast, requires almost daily monitoring of nutrient levels since substrates provide no nutrients or buffering capacity.

Soil testing laboratories use different methods to extract plant-available nutrients. For this reason, results are not directly comparable from one laboratory to another. In addition, extractants used for estimating available P, K, Ca, and Mg are not appropriate for estimating levels of micronutrients. Therefore, soil test results for most micronutrients have little meaning.

Soil test recommendations for strawberries are ballpark estimates of fertilizer needs because crop response data for each nutrient on different soil types have not been generated. Most growers assume a higher level of precision in soil tests than actually exists. A soil test approximates nutrient needs, but it cannot really be used to fine-tune a fertilizer program.

Terms Used in Interpreting Soil Tests

- **pH** is the relative acidity or alkalinity of a soil. A pH of 7 is neutral, a pH less than 7 is acidic, and a pH greater than 7 is alkaline.
- **Cation** is a positively charged ion. The most common in soils are calcium (Ca), potassium (K), magnesium (Mg), and aluminum (Al).
- **Cation Exchange Capacity (CEC)** is the measure of the ability of a soil to adsorb Ca, K, and Mg ions (among others) and of its resistance to change pH in response to liming or sulfur additions. Clays and soils high in organic matter tend to have a high CEC, whereas sands have a low CEC.
- **Base Saturation** is the percentage of the exchange sites that contain a calcium, potassium, magnesium, or other cation. The higher the percent base saturation, the higher the pH.

Foliar Analysis

Since soil tests are of limited value in estimating N availability, plant tissue analysis is more commonly used to measure the amount of nutrients in plant parts. Recommendations are based on the nutrient levels at specific times of the year. Sufficiency ranges are known for strawberries based on years of observations in healthy and productive plantings (table 7-2). Unlike visual diagnoses, foliar nutrient analyses can alert the grower when nutrient levels are approaching deficiency so corrective action can be taken. Unlike soil tests, foliar analyses provide results for all essential mineral nutrients, including micronutrients.

Currently, recommendations are based on newly expanded leaves collected after renovation in late July or early August. Other sampling times or plant parts may prove to be more appropriate for certain nutrients; but until more detailed studies are done, foliar samples collected in mid-summer are the standard because levels are most stable then. For day-neutral varieties, more frequent foliar testing is recommended, but at least 1 mid-summer test can help ensure the fertilizer program is sufficient.

Collect at least 50 leaves, remove their petioles, and wash them in distilled water. Dry them, place them in a paper bag, and send them to the laboratory for analysis. Samples should be representative of the entire field. If a particular area of the field looks poor or has been fertilized differently from the rest, sample it separately.

Sap Analysis

Some growers test the nitrogen levels in petiole sap to determine nitrate levels, then adjust accordingly. However, levels fluctuate considerably in strawberry and have not been found to support reliable recommendations.

The Best Approach

A combination of soil testing, tissue analysis, and observation of crop response is the best approach to assessing nutrient status. Prior to planting, conduct a soil test and amend the soil according to recommendations. After planting, conduct a foliar tissue analysis at least every other year. The soil pH should be monitored regularly, and a complete soil test performed before any new planting. Always be alert for any unusual-looking leaves and unexplained reductions in growth or yield.

Table 7-2. Sufficiency ranges for foliar nutrient levels in strawberry leaves in midsummer (perennial systems).

Nutrient	Deficient Below	Sufficient	Excess
N (%)	1.9	2.0–2.8	4.0
P (%)	0.2	0.25–0.4	0.5
K (%)	1.3	1.5–2.5	3.5
Ca (%)	0.5	0.7–1.7	2.0
Mg (%)	0.25	0.3–0.5	0.8
S (%)	0.35	0.4–0.6	0.8
B (ppm)	23	30–70	90
Fe (ppm)	40	60–250	350
Mn (ppm)	35	50–200	350
Cu (ppm)	3	6–20	30
Zn (ppm)	10	20–50	80

Soil Amendments

Many materials are useful as soil amendments: fertilizers, lime, manure, composts, green manures, and others. Each has unique properties that are beneficial under certain circumstances.

Lime

Liming affects soil pH, which strongly influences nutrient uptake and plant growth. Proper liming can increase soil productivity and increase the efficiency of other fertilizers. Lime also provides Ca and possibly Mg, depending on the source. Lime is used to balance the acidification that occurs when certain fertilizers, manures, or composts are used (table 7-3). Other materials may contain Ca and Mg (for example, gypsum) but they do not influence soil pH significantly.

The proper amount of lime to apply depends on the soil test recommendation (see Chapter 2). Not all limestone is the same—some is less pure than others. The purity is indicated by the calcium carbonate equivalent (CCE). If a particular limestone has a CCE of 80%, then 5 tons per acre would be applied if the soil test recommended 4 tons (4 tons ÷ 0.80 = 5 tons). Limestone also differs with respect to the speed at which it reacts with the soil. The more finely ground the limestone, the faster it reacts, so particles should be smaller than a 20-mesh size—preferably of 100-mesh size.

In addition, if the soil test recommends Mg, a high-Mg lime (dolomitic lime) should be used, even though it may be more expensive. Finally, lime is sold by weight; if the limestone is not completely dry, adjust application rates accordingly (that is, increase rates by the percentage of moisture in the lime).

Manure

Manure is a source of both nutrients and organic matter and can significantly improve soil structure. If it is readily available, manure can replace some synthetic fertilizers and save money.

The urea in manure is unstable and will volatilize quickly unless incorporated into the soil. The solid organic fraction decomposes more slowly and provides N over a long period of time—even into subsequent years. However, in most situations, insufficient N is released from manure in any one year to equal that provided by synthetic fertilizers.

To meet the total requirements of the strawberry plant during critical periods of crop growth (table 7-4), manure supplemented with N fertilizer has provided better results than manure used alone. Manure spread in autumn should be applied over a cover crop, which helps retain much of the N from manure that otherwise might be lost to leaching and runoff. Providing sufficient N is one of the biggest challenges for organic growers as strawberries root systems are not efficient at taking up nitrogen compared to many other plants.

Manure is also a source of organic P and K, but these nutrients are released slowly as the organic matter decomposes. However, in a field that has received manure applications over a long period of time, available P should be high and perhaps excessive. Growers who use manure for fertilizer should monitor Mg levels closely, because manure is not a good source of Mg.

Food Safety Considerations for Manure Application

While manure is an excellent source of plant nutrients and organic matter, manure is also a source of pathogens such as *E. coli* and *Salmonella*, which can contaminate fruit. The Food Safety Modernization Act (FSMA) Produce Safety Rule provides guidelines for application of untreated Biological Soil Amendments of Animal Origin (BSAAO) to minimize contamination of produce. Any soil amendment that arises from animals or animal products (such as manure, feather meal, bone meal, or other products) and has not been treated to reduce pathogens (through composting, heat treatment, or other means) is considered to be an untreated BSAAO. To prevent microbial contamination from manure and other untreated BSAAO, growers should practice the following:

- When possible, properly compost fresh manure to kill pathogens prior to application. Keep records to document turning of the pile and temperature. If purchasing BSAAO from a third party supplier, request documentation of treatment processes.
- Never sidedress with fresh manure prior to harvest. Manure should be applied to the strawberry crop no less than 120 days prior to harvest. A reduced interval may be used for treated amendments.
- Apply fresh manure in the fall to a cover crop rather than to bare ground.

Table 7-3. Equivalent acidity and alkalinity of nitrogenous fertilizer materials.

Material	% Nitrogen	Pounds of Pure Lime for Neutralization	
		Per Pound of Nitrogen	Per 100 Pounds of Material
Inorganic sources of nitrogen			
Sulfate of ammonia	20.5	5.35	110
Ammo-phos A	11.0	5.00	55
Anhydrous ammonia	82.2	1.80	148
Calcium nitrate	15.0	1.35	20
Nitrate of soda	16.0	1.80	29
Potassium nitrate	13.0	2.00	26
Manufactured organic nitrogen			
Cyanamid	22.0	2.85	63
Urea	46.6	1.80	84
Natural sources of organic nitrogen			
Cocoa shell meal	2.7	0.60	2
Castor pomace	4.8	0.90	4
Cottonseed meal	6.7	1.40	9
Dried blood	13.0	1.75	23
Fish scrap	9.2	0.90	8
Guano, Peruvian	13.8	0.95	13
Guano, white	9.7	0.45	4
Milorganite sludge	7.0	1.70	12
Cu (ppm)	3	6–20	30
Zn (ppm)	10	20–50	80

Table 7-4. Percentage of manure nitrogen available to crops in the current year.

Time of Application	Poultry	Cow
Incorporation the same day	75	50
Within 1 day	50	40
Within 2–4 days	45	35
Within 5–6 days	30	30
After 7 days	15	20
Applied previous fall		
Without a cover crop	15	20
With a cover crop	50	20

Compost

Compost is partially decomposed organic matter that provides a source of nutrients and organic matter to plants. Because of the loss of water and carbon dioxide that occurs during the composting process, the quantity of the final product is much less than that of the raw materials, but compost will contain a higher concentration of N, P, and K. However, N is less available in compost compared to manure, because less is in the ammonium form and more is in the residual organic form. For example, whereas 35% of manure N might be available in the year the manure is spread, only 10% of the N in compost is available.

Compost has properties that make it potentially beneficial for strawberry growers beyond the nutrient contribution. Compost improves soil structure and water-holding capacity, and some composts suppress diseases because of the high level of microbiological activity they contain. Composted manure presents a reduced health hazard and is odor-free.

Green Manure

Green manure is a term used to describe a cover crop that is grown for the purpose of incorporation into the soil. An incorporated cover crop provides organic matter, which improves soil structure and water-holding capacity. Cover crops can also sequester residual N that is released from or applied to the soil. Green manures with a high N content (such as legumes) decompose quickly. Those with a low N content (such as cereal grains) decompose more slowly, tying up N for a period of time. Strawberries should not be planted immediately after incorporation of a green manure or after a previous planting that was heavily mulched with straw as they could experience "nitrogen drag."

Individual Nutrients

Nitrogen (N)

June-bearing strawberry plants have an increasing demand for N throughout the establishment year; therefore, a constant supply of N is required for optimal growth. In the fruiting year, N applications in the spring can be detrimental. Spring N applications of more than 30 lbs/acre can result in an increase in gray mold and mites and a reduction in fruit quality (firmness). Thus, for June-bearers, the best time to apply N is immediately after fruiting, with supplementation in late summer to maintain N availability through autumn.

Nitrogen sources include ammonium-based fertilizers, nitrate fertilizers, organic sources, and organic matter (table 7-5). The amount of N released from organic matter can be significant. Plants tend to grow better in soils high in organic matter (greater than 6 percent) than those low in organic matter (less than 2 percent), even with supplemental N fertilization. Most commercial growers apply synthetic fertilizers, even when organic matter is high. This ensures adequate amounts of N are available at critical times.

Fertilizer N is available to the plant in 2 forms: nitrate and ammonium. The strawberry preferentially takes up nitrate N over the ammonium form. Nitrate N is highly water soluble, making it subject to leaching, and it is generally more expensive than ammonium-based fertilizers. Therefore, many fertilizers contain the ammonium form of N because it is less expensive to manufacture and soil organisms eventually convert the ammonium form into the nitrate form. Some ammonium-based fertilizers are coated with S or synthetic resin to further slow the release of N to the plants and extend its availability. These fertilizers are expensive because the ammonium ion has a positive charge, it tends to be adsorbed to soil colloids and is less easily leached. Ammonium-based fertilizers are commonly used in strawberry production even though they tend to acidify the soil (table 7-3).

In newly planted fields, use calcium nitrate for fertilization, especially if the site was fumigated prior to planting. Calcium nitrate is a readily available form of N and is not subject to volatilization. On well-established plantings, other sources of N are suitable. Many growers prefer ammonium nitrate because it provides for both a rapid response (in the form of nitrate) and a slow-release (in the form of ammonium), but it is not readily available due to its explosive properties. Urea is usually the least expensive N source, but it is subject to volatilization under certain conditions (hot and wet). If volatilization occurs, N may be lost to the air. Volatilized ammonia can blacken strawberry leaves since they are close to the soil where the fertilizer was applied. Incorporating urea immediately after application will prevent this loss.

Foliar applications of urea are of limited value in strawberries. Although some N can be absorbed through the leaves, only a small amount can be applied at any one time, usually less than 2 lbs/acre actual N. Therefore, the utility of foliar applications of N for correcting deficiencies is limited.

Table 7-5. Typical composition of some common chemical sources of fertilizer nitrogen and potassium.

Source	%N	%P_2O_5	%K_2O	%MgO	%S
Ammonium sulfate	21	-	-	-	24
Anhydrous ammonia	82	-	-	-	-
Ammonium chloride	25–26	-	-	-	-
Ammonium nitrate	33–34	-	-	-	-
Ammonium nitrate-sulfate	30	-	-	-	5–6
Ammoniated ordinary superphosphate	4	16	-	0.5	10
Monoammonium phosphate	11	48–55	-	0.5	1–3
Diammonium phosphate	18–21	46–54	-	-	-
Ammonium phosphate-sulfate	13–16	20–39	-	-	3–14
Calcium nitrate	15	-	-	-	-
Potassium nitrate	13	-	44	0.5	0
Sodium nitrate	16	-	-	-	-
Urea	45–46	-	-	-	-
Potassium chloride	-	-	60–62	-	-
Potassium sulfate	-	-	50–52	-	17
Potassium magnesium sulfate	-	-	22	11	22
Potassium nitrate	13	-	44	-	-
Potassium and sodium nitrate	15	-	14	-	-
Manure salts	-	-	22–27	-	-
Potassium hydroxide	-	-	83	-	-
Potassium carbonate	-	-	<68	-	-

A typical N fertilization regime for June-bearing strawberries is:

Year 1: 30 lbs/acre 4 weeks after planting
40 lbs/acre in early September

Year 2: 70 lbs/acre immediately after fruiting
30 lbs/acre in early September

If applied weekly, use as a starting point of 4 lbs/acre actual N per week between early May and mid-September of the planting year, and 10 lbs/acre actual N per week between mid-July and mid-September of the fruiting year. This amount would be typical for a sandy loam soil with 3% organic matter content. Plants growing on sandier soils might require more, and plants in heavier soils with high organic matter content will require less. Adjust application rates up or down depending on the results of a leaf analysis. In general, growers in the Northeast provide adequate N to strawberry plants. Only about 1% of leaf samples show inadequate N. If the foliar leaf level in late July or early August is below 2% N, then increase the current N application by 10% for each 0.1% that the sample is below 2%. This additional N can be applied in early September. In certain situations, a small October application might be beneficial. Nitrogen deficiency leads to smaller plants, the older leaves of which develop a reddish color (photos 7-1 and 7-2). Symptoms are most apparent in late summer.

Photo 7-1. Nitrogen deficiency in a leaf (G. May).

Phosphorus (P)

The total amount of P in the soil averages about 900 lbs/acre across all soil types, but only a fraction is available for plant growth. Much of the P is tied up in soil minerals, insoluble precipitates, and organic matter. Little P is dissolved in the soil solution, so most uptake occurs through diffusion. Good root growth is required for the plant to obtain an adequate surface area to facilitate P uptake. Strawberries tend to have a low demand for P relative to other crops. Only a small percentage of commercial fields are deficient in P; in most cases, excess P is more of a concern.

Photo 7-2. Nitrogen deficiency in a field (G. May).

Phosphorus tends to react with cations in the soil solution, forming insoluble precipitates with Fe, aluminum (Al), Ca, and Zn. Excess P fertilization can result in micronutrient deficiencies.

Phosphorus availability is affected by soil pH, soil moisture, soil type, organic matter content, the amount of Ca and Al in the soil, and soil temperature. Extremes in pH, temperature, and moisture can limit availability, as can excessive Ca and Al. Soils with a large quantity of clay will fix more P than lighter soils. Certain microorganisms can increase P availability, including phosphobacteria and some mycorrhizal fungi. Humic acids from organic matter decomposition increase the solubility of P. Available P is increased after incorporating a green manure, even though no additional P will have been added.

Because inorganic P has a low solubility in water, it is not subject to leaching. However, it must be incorporated to be effective. Phosphorus fertilizers (table 7-6) applied to the soil surface will not move into the root zone within a useful time period. Preplant incorporation is necessary. Large fertilizer granules are slow to break down; so for maximum effectiveness, uniformly distribute small granules throughout the root zone. Keep soil pH near 6.5 to ensure that P is available. Phosphorus can be applied though a drip irrigation system in the form of phosphoric acid. Materials containing P are incompatible with many other fertilizers. Use caution when applying through a drip irrigation system.

Plants deficient in P develop a purplish cast in older leaves. Younger leaves may turn dark green (photo 7-3). Foliar P levels tend to decline after fruiting. If P levels are low in July, then apply 100 lbs/acre in a form that is readily available to the plant (table 7-6).

Potassium (K)

Strawberries require a large amount of K as it is a major component of fruit. Much more K is present in the soil than is available to the plant. For example, soils may average 25,000 ppm, but the concentration in the soil solution may be only 10 ppm. Soil tests estimate the amount of K on exchange sites, which is also available for plant uptake. This amount is variable but can be up to 600 ppm. Since little K is dissolved in solution, diffusion is the most important mechanism of uptake. Therefore, good root development is essential to increase the surface area through which the K can diffuse.

The availability of K depends on soil chemistry. The amount of organic matter, the soil texture, the type of clay, and the mineral base also influence availability. In most cases, increasing the organic matter will increase exchange capacity, allowing more K to be adsorbed to the exchange sites. Negatively charged clays also provide exchange sites for K; however, certain clays can trap K ions between

Table 7-6. Composition of phosphatic fertilizer materials.

Material	Total N (%)	Total K (%)	Total S (%)	Total Ca (%)	Total Mg (%)	P	
						Total (%)	Available* (% of total)
Ordinary super- phosphate	-	-	11–12	18–21	-	7–9.5	97-100
Triple super-phosphate	-	-	0–1	12–14	-	19–23	96-99
Enriched super-phosphate	-	-	7–9	16–18	-	11–13	96–99
Dicalcium phosphate	-	-	-	29	-	23	98
Superphosphoric acid	-	-	-	-	-	34	100
Phosphoric acid	-	-	0–2	-	-	23	100
Potassium phosphate	-	29–45	-	-	-	18–22	100
Ammonium phosphate nitrate	30	-	-	-	-	4	100
Ammonium poly-phosphate	15	-	-	-	-	25	-
Magnesium ammonium phosphate	8	-	-	-	14	17	-
Raw rock phosphate	-	-	-	33–36	-	18–32	2–3

* By neutral 1.0N ammonium citrate procedure.

layers when they dehydrate. High levels of other nutrients, such as Ca and Mg, can replace K on the exchange sites. A balance among these 3 cations is necessary for proper nutrition.

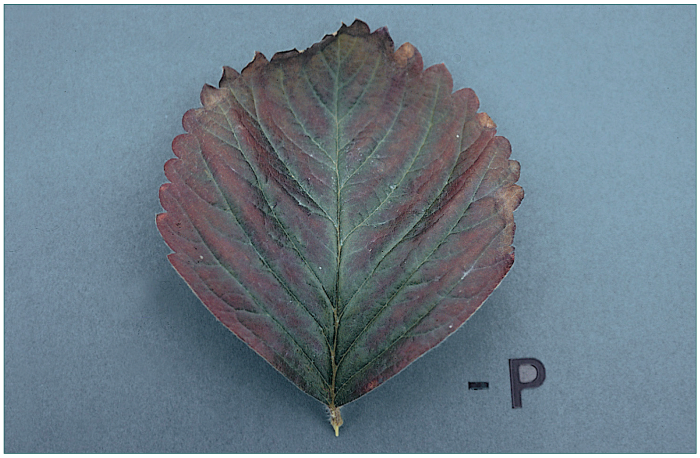


Photo 7-3. Phosphorus deficiency in a leaf (G. May).

Preplant incorporation of K (table 7-5) is most effective, while fertigation can be used to supply K in established plantings. Surface applications of K fertilizers are of limited value for short-term crops such as strawberries. Foliar uptake is possible, although the total amount that can be supplied through this method in a single application is small. Sequential applications are effective but expensive.

Potassium is required for many physiological processes in the plant, including enzyme activation, transport of sugars, stomatal functioning, charge balance, protein synthesis, and photosynthesis. Deficiencies occur on older leaves first and result in marginal necrosis. Leaflet petioles may become necrotic also, and leaflets may darken (photo 7-4). Potassium levels in leaves tend to fluctuate during the season and decrease as crop load increases. If foliar levels are low, then supplemental K can be added with the amount dependent on soil type. A reasonable supplement in a sandy soil is 100 lbs/acre; in a heavier soil, half that amount can meet K needs. Fall application is preferred. Excess K can induce a Mg deficiency, so if the K/Mg ratio in leaves exceeds 4, then additional Mg should be applied if K is also applied. If more than 100 lbs/acre of K is required, potassium sulfate is recommended over potassium chloride (muriate) to avoid chloride toxicity.

Sulfur (S)

Sulfur occurs in elemental form, as well as in sulfides, sulfates, and organic combinations with carbon and N. The majority of S comes from decomposing organic matter, although a significant amount is dissolved in rain, up to 100 lbs/acre annually. Most is absorbed by mass flow. Because S availability is associated with carbon and N cycling, large annual variations occur, giving soil tests limited value under most conditions.

Sulfur is an essential component of proteins; when S is deficient, overall plant vigor is decreased and leaves turn a reddish color (photo 7-5). When acid rain was abundant in the Northeast, S deficiencies were rare. Recent decades have seen less acid rain and more S fertilizer use on farms.

The major use of S for strawberry growers is for pH reduction. If soils are too alkaline, the addition of S will lower the pH. Sulfur is oxidized by bacteria into sulfuric acid, which helps to neutralize basic ions such as Ca and Mg. The size of S granules is the major factor influencing the rate of soil pH change. After ninety days, only about 1% of the S will react if the granules are unable to pass through a 10-meshes-per-inch screen (0.2 inch diameter), whereas nearly half will react if the size is less than 100 meshes per inch.

Photo 7-4. Potassium deficiency (G. May).

Calcium (Ca)

Calcium is a major component of pectin, the strengthening agent of cell walls. Without sufficient Ca, fruit are soft, and the leaf tips turn brown and do not completely expand. In severe cases, runner plants turn brown and new leaves develop interveinal necrosis (photos 7-6, 7-7, and 7-8).

Symptoms of Ca deficiency are common, but this is rarely due to insufficient Ca in the soil. Ca mobility is limited, both in the soil and in the plant, and the factors affecting mobility indirectly influence Ca uptake. Calcium can enter the plant only through unsuberized root tips—not along the entire length of root. Therefore, factors that limit mass flow, such as low soil moisture and cool, cloudy, humid weather, can reduce the amount of Ca entering the plant to below critical levels. Since Ca movement within the plant is also limited, deficiencies occur in new growth at points farthest from the root system.

Photo 7-5. Sulfur deficiency (G. May).

Adequate Ca is usually present if the soil pH is within an acceptable range. With drip irrigation, Ca can be leached out of the wetted zone over time. In most cases, though, maintaining good soil moisture is the best way to prevent tip burn associated with Ca deficiency.

Apply adequate limestone prior to planting to adjust the soil pH to 6.0–6.5. In lighter soils, more Ca may be required than is needed for pH adjustment. If Ca is required but the pH is already high, gypsum can be used as a Ca source. Over a 5-year period, as much as 2,000 lbs of Ca can be leached out of the root zone. Accommodation for this drop in Ca, and concomitant drop in pH, should be anticipated prior to planting.

Many growers apply foliar calcium chloride sprays before harvest to increase fruit firmness, but this has not been documented to be effective in controlled studies where plants are not deficient in calcium.

Photo 7-6. Mild calcium deficiency in a leaf (G. May).

Photo 7-7. Severe calcium deficiency in a leaf (G. May).

Photo 7-8. Calcium deficiency in a runner (K. Orde).

Magnesium (Mg)

Magnesium supply varies widely from soil to soil. Deficiencies are common, especially on sandy, acidic soils. Magnesium is an essential element in chlorophyll, and without it the plant turns yellow, starting with interveinal areas on older leaves (photo 7-9). Cold, wet, cloudy weather induces Mg deficiency in marginal situations, since uptake is mainly by mass flow.

Photo 7-9. Magnesium deficiency (G. May).

Magnesium availability increases with soil pH up to 8.5 (figure 7-2). Magnesium can be relatively unavailable at a low pH. Also, high levels of Al can reduce Mg availability, and excessive K can induce Mg deficiency. A K/Mg ratio of less than 5 is desirable. If this ratio is high, additional Mg could be beneficial even if Mg is within the desired range. Since Mg is fairly soluble, it can be effectively applied to leaves (depending on the formulation, at 5 pounds actual Mg per acre) or to the soil surface (at 40 lbs/acre). It can also be preplant incorporated (as dolomitic lime or Epsom salts). The least expensive source of Mg is dolomitic lime and the most soluble and readily available form is Epsom salts.

Iron (Fe)

Iron is the fourth most abundant element in the Earth's crust, but concentrations in soils vary widely. Much of the Fe in soil is in the insoluble ferric form (Fe^{3+}), which is unavailable to plants. Available Fe in the ferrous form (Fe^{2+}) is obtained from clays, minerals, and hydroxides. Root exudates, microbial byproducts, and organic matter are natural chelates that can increase Fe availability up to threefold. Iron becomes more available with decreasing soil pH. Excessive liming can induce an Fe deficiency, which results in yellowing of younger leaves, as Fe is involved with chlorophyll synthesis (photo 7-10). Excess P can form insoluble precipitates with Fe. Nitrogen sources also affect Fe availability. Fertilization with ammonium sources of N tends to decrease soil pH around the root zone, thereby increasing Fe availability.

Rarely is an Fe-containing, soil-applied fertilizer required to relieve a deficiency. Acidification of soil is the most cost-effective way to increase Fe availability. Foliar applications are useful during the time when soil pH is being lowered; formulations vary, so follow the label directions.

Photo 7-10. Iron deficiency (G. May).

Manganese (Mn)

Manganese is widely distributed in northeastern soils. With the exception of the mid-Atlantic coastal plain, few soils are inherently low in this nutrient. However, across the United States, Mn is one of the most commonly deficient micronutrients. Manganese availability is strongly associated with soil pH, and deficiencies most often occur on alkaline soils or on soils that have been heavily limed. In some soils, toxicity can occur if the pH is too low. Strawberries are very tolerant to extremes in Mn levels, so this nutrient is of little concern to most growers.

If Mn is deficient, soil pH should be lowered to below 5.5. Foliar sprays may temporarily relieve a deficiency, which is characterized by generally poor growth without distinguishing symptoms.

Boron (B)

Boron is the only nonmetal among the micronutrients and usually does not occur as a charged ion. This, coupled with its small size, makes it especially prone to leaching. In coarse-textured soils that are low in organic matter, up to 85% of the available B can be leached with only 5 inches of water. The level of B in soil varies widely, so B is one of the most commonly deficient micronutrients in strawberry plantings. Furthermore, soils naturally low in B occur throughout the United States and Canada.

Boron is essential for root growth (photo 7-11). If root growth is poor (photo 7-12), deficiencies of other nutrients can develop, and plants become stunted. Plants deficient in B show asymmetrical leaf growth (photo 7-13), and berries can be deformed despite adequate pollination (photo 7-14). Foliar levels tend to decline during the season. If a foliar analysis indicates 30 ppm B or less early in the season, levels may be inadequate to sustain the plants through fruiting. To supplement soil B, apply no more than 1 pound of actual B per acre-year. Uptake occurs through leaves and roots, so the best time to apply B is after leaves are mowed at renovation. Blending granular B with other fertilizers makes application easier. A typical foliar application is 1 ½ lbs/acre solubor (20% B) in 100 gallons of water.

Mass flow is the most important mode of uptake for B, so conditions not favoring water uptake may induce a deficiency. Levels of other nutrients, especially too much P, have been reported to affect B uptake.

Photo 7-11. Root system with adequate boron (G. May).

A narrow range exists between deficient and toxic B levels. Toxic levels sometimes accumulate with irrigation in arid climates or where overapplication has occurred. Hard, yellowish berries and uneven ripening can result if levels exceed 100 ppm.

Photo 7-12. Root system without adequate boron (G. May).

Photo 7-13. Asymmetrical leaf growth without adequate boron (G. May).

Photo 7-14. Boron deficiency symptoms in fruit (G. May).

Zinc (Zn)

Zinc deficiency is widespread in North America. Total soil Zn is not a good predictor of availability to plants, as Zn has a strong tendency to combine with anions in the soil to form insoluble precipitates. Zinc is also complexed by organic matter, which can reduce availability in certain circumstances. Zinc availability increases as soil pH decreases.

Zinc functions in enzyme activation and synthesis of growth regulators. Plants with Zn deficiency are stunted, have narrow leaves, and tend to accumulate high levels of P. Some evidence suggests that plants perform poorly if the P/Zn ratio is greater than 140.

Zinc is relatively immobile in the soil; so preplant applications such as zinc sulfate, although effective, can be expensive. Soil surface applications are not effective. Sequential foliar applications can be the least expensive means of supplying Zn. Fertigation also may be an effective way to increase plant Zn levels.

Copper (Cu)

Copper is one of the least mobile nutrients in soil or plants. For this reason, when Cu is deficient, corrections are difficult. Although a significant amount of soil Cu is insoluble, a significant pool may be complexed with natural organic chelates. This pool is available for plant uptake.

Only small areas of North America contain soils that are inherently low in Cu. However, high soil pH and excessive P, Zn, and Al restrict Cu absorption and translocation. Furthermore, Cu adsorption to Fe, Al, and Mn oxides can be significant. The dynamics of Cu in the soil are complex.

Visual symptoms of Cu deficiency are not distinctive, although Cu is an essential component of many enzyme systems. Foliar levels above 7 ppm are considered adequate, but no response to applications have been reported when levels are above 3 ppm.

Copper is toxic to both roots and leaves, so remedial action can cause more harm than good. Foliar Cu applications can burn leaves, so small amounts of chelated forms are recommended. However, because of low mobility, foliar levels may not increase in response to foliar applications.

Molybdenum (Mo)

Molybdenum is an important component of enzymes involved with N metabolism, but levels in the soil are very low. The plant needs only small amounts of Mo (<1 ppm), so deficiencies are common only in acidic, sandy, leached soils. Foliar applications are effective for providing the small amounts required.

Fertilizer Sources

Many types of fertilizer can be used in strawberry plantings provided that they meet the nutrient requirements of the plant. Organic sources of nutrients may be obtained easily (table 7-3) and often improve soil organic matter at the same time. However, the release rate of nutrients from organic fertilizers is often slow, and large amounts of fertilizer are required to meet requirements for optimum growth. Concentrated synthetic fertilizers usually are easier to apply are more consistent in composition (tables 7-5, 7-6, and 7-7); and release nutrients quickly. The disadvantages of synthetic fertilizers are that they often have a high salt index (they can burn the plant); they are subject to leaching; and they may contain chlorides that are toxic at high levels. Fertilizers should be used sparingly in young plantings because of sensitivity to salts. Calcium nitrate is recommended on first-year plantings as a N source because it is readily available to new plants and does not have to be converted by bacteria to a useable form. Avoid ammonium sources if the field was recently fumigated.

Many fertilizers tend to acidify the soil; so, if large amounts are applied, additional lime may be necessary to buffer against pH changes (table 7-3). Fertilizers are available that contain micronutrients (table 7-7); but in many cases, micronutrients become fixed in soil and are unavailable to the plant shortly after application. For this reason, chelates and fertigation are the preferred application methods for micronutrients—if they are deficient.

Table 7-7. Inorganic compounds commonly used as micronutrient sources.

Micronutrient Source	Solubility in Water	Percent Element
Boron (B)		
$Na_2B_4O_7$ (anhydrous borax)	Soluble	20
$Na_2B_4O_7 \cdot 5H_2O$ (fertilizer borate)	Soluble	14
$Na_2B_4O_7 \cdot 10H_2O$ (borax)	Soluble	11
H_3BO_3	Soluble	17
Copper (Cu)		
$CuSO_4 \cdot H2O$	Soluble	35
$CuSO_4 \cdot 5H2O$	Soluble	25
$CuSO_4 \cdot 3Cu(OH)_2 \cdot H_2O$	Insoluble	37
CuO	Insoluble	75
Iron (Fe)		
$FeSO_4 \cdot H_2O$	Soluble	33
$FeSO_4 \cdot 7H_2O$	Soluble	20
$Fe_2(SO_4)3 \cdot 9H_2O$	Soluble	20
$FeSO_4 \cdot (NH_4)2\ SO_4$	Soluble	22
Manganese (Mn)		
$MnSO_4 \cdot 4H_2O$	Soluble	26–28
$MnCl_2$	Soluble	17
$MnCO_3$	Insoluble	31
MnO_2	Insoluble	41–68
Molybdenum (Mo)		
Na_2MoO_4 (anhydrous)	Soluble	47
$Na_2MoO_4 \cdot 2H_2O$	Soluble	39
$(NH^4)^2MoO^4$	Soluble	49
MoO_3	Insoluble	66
$CaMoO_4$	Insoluble	48
Zinc (Zn)		
$ZnSO_4 \cdot H_2O$	Soluble	36
$ZnSO_4 \cdot 7H_2O$	Soluble	22
$ZnCl_2$	Soluble	47
$ZnSO_4 \cdot 4Zn(OH)_2$	Slightly soluble	55
$ZnCO_3$	Insoluble	52
ZnO	Insoluble	6078

Chelated Nutrients

Chelate is derived from a Greek word meaning claw and is used to describe metallic cations complexed to large organic molecules. Complexed ions are protected from reaction with inorganic constituents that would make them unavailable for uptake by plants. Plant roots exude chemicals that act as chelates. Chelates can result from the breakdown of organic matter, or they can be synthesized. Zinc, Cu, Mn, and Fe are among the essential plant micronutrients that form chelates with organic molecules.

Chelates vary in their stability and suitability as sources of micronutrients. Under most conditions, Fe chelates are more stable than those of Zn and Cu, which in turn are more stable than Mn chelates. This is because Fe has a higher affinity for chelates. If Cu chelate is added to a soil high in Fe, the Fe may displace the Cu, rendering the Cu subject to soil reactions. Therefore, the ability of chelates to increase nutrient availability depends on the level of other available cations. With foliar applications, the organic chelates are less reactive and cause less phytotoxicity. However, because of their large size, their movement into a leaf is more limited than with inorganic salts.

Fertigation

Fertigation is often the most effective way of providing certain micronutrients to strawberries (table 7-8). Applications can be more uniform than with ground equipment and can be made during any weather. Less fertilizer is usually required as well. Systems are available to meter out fertilizer solution at the appropriate time and in correct amounts. Disadvantages include the capital expense and time to set up and calibrate the system. The potential for leaching is greater with fertigation, and it is highly regulated by most states. Drip irrigation systems are susceptible to plugging if improper fertilizer materials are used.

The amount of fertilizer to apply to June-bearing strawberries is dependent on many factors, but a starting point is 4 lbs/acre actual N per week between early May and mid-September of the planting year, and 10 lbs/acre actual N per week between mid-July and mid-September of the fruiting year. This amount should be adjusted accordingly if granular fertilizers are used. Other nutrients can be added if a leaf analysis indicates the need. For day-neutral strawberries, 5–7 lbs/week is required to maintain production through the season.

If fertigation is to be used, consider water quality and uniformity of water application by the system. Water low in salts, suspended particles, and bacteria is essential, as is a system designed to deliver equivalent amounts of water throughout a field. Trickle Irrigation in the Eastern United States will assist in designing a drip irrigation system.

Irrigation lines should be filled with water before injecting fertilizers, then flushed after injection is complete. Fertigation should occur near the end of the irrigation cycle to prevent leaching. Flush lines thoroughly between different fertilizers to avoid incompatibility problems (see sidebar below). Chlorination may be required to control algae and bacterial slime that can plug emitters. Fertigation should not be used to correct major soil nutrient and pH problems; this should be done before planting.

Combinations of certain nutrients can form insoluble precipitates with each other, plugging the emitters and causing misery for the operator. To determine if chemicals are compatible, shake them together in a jar to determine if precipitation occurs.

While there is much to understand to be able to manage soil health and nutrition, tools exist to assist in making decisions about application timings and rates. A soil test coupled with foliar tests provide a robust guide to providing the information required to make an informed decision about the fertilizer program.

Nutrient Compatibility

Below are some rules regarding compatibility:

- Do not mix Ca products with those containing phosphates or sulfates.
- Do not mix Mg, Zn, Fe, or Cu products with products that contain phosphates. Water naturally high in Fe can be a problem, so the Fe must be removed prior to injection of P fertilizers.
- Do not mix Fe chelates with other chelated products.

Table 7-8. Materials for fertigation and their solubilities.

	Solubility (pounds/gallon water)
A. NITROGEN	
Ammonium nitrate (33.5-0-0) [NH_4NO_3]	9.8 @ 32˚F
Ammonium sulfate (20-0-0) [$(NH_4)_2SO_4$]	5.9 @ 32˚F
Calcium nitrate (15-0-0 + 22%Ca) [$Ca(NO_3)_2$]	10.1 @ 64˚F
Magnesium nitrate (11-0-0 + 9.5%Mg) [$Mg(NO_3)_2$]	3.5 @ 64˚F
Potassium nitrate (13-0-45) [KNO_3]	1.1 @ 32˚F
Sodium nitrate (16-0-0) [$NaNO_3$]	6.1 @ 32˚F
Urea (44-0-0) [NH_2CONH_2]	6.5 @ 41˚F; 10 @ 77˚F
B. POTASSIUM	
Potassium chloride (muriate of potash) (0-0-60) [KCl]	2.9 @ 68˚F
Potassium nitrate (13-0-45) [KNO_3]	1.1 @ 32˚F
Potassium sulfate (0-0-48–54 + 16–18%S) [K_2SO_4]	0.6 @ 32˚F; 1.0 @ 77˚F
C. PHOSPHORUS	
Phosphoric acid (0-55–77-0) [H_3PO_4]	43.1 (liquid)
Mono-potassium phosphate (0-52-35) [KH_2PO_4]	2.75 @ 77˚F
Diammonium phosphate (DAP) (21-54-0) [$(NH_4)2HPO_4$]	3.5 @ 32˚F
Mono-ammonium phosphate (MAP) (11-48-0) [$NH_4H_2PO_4$]	1.9 @ 32˚F
Mono-calcium phosphate (0-53-0 + 16%Ca) [$Ca(H_2PO_4)_2$]	0.15 @ 86˚F
D. CALCIUM	
Calcium nitrate [$Ca(NO_3)_2$]	10.1 @ 64˚F
Hydrated lime [$Ca(OH)_2$]	0.02 @ 68˚F
E. MAGNESIUM	
Epsom salts (10%Mg and 13%S) [$MgSO_4 \cdot 7H_2O$]	5.9 @ 32˚F
Magnesium nitrate (9.5%Mg) [$Mg(NO_3)_2$]	3.5 @ 64˚F
F. BORON	
Solubor (20.2%B)	1.0
Boric acid (17.5%B) [H_3BO_3]	0.5 @ 86˚F; 2.3 @ 212˚F
Borax (11.3%B) [$Na_2B_4O_7 \cdot 10H_2O$]	0.13oz @ 32˚F; 14lbs @212˚F
G. MANGANESE	
Manganese sulfate (24.6%Mn) [$MnSO_4 \cdot 4H_2O$]	8.7 @ 32˚F
Manganese chelates (up to 12%Mn)	-
H. IRON	
Iron chelates (up to 10%Fe)	-
Ferrous sulfate (20%Fe + 11.5%S) [$FeSO_4 \cdot 7H_2O$]	1.3
I. ZINC	8.0
Zinc sulfate (23%Zn + 11%S) [$ZnSO_4 \cdot 7H_2O$]	-
Zinc sulfate monohydrate (36%Zn + 18%S) [$ZnSO_4 \cdot H_2O$]	-
Chelated zinc products (up to 14%Zn)	
J. COPPER	
Copper sulfate (25%Cu + 13%S)	2.6 @ 32˚F
Chelated copper products (up to 13%Cu)	-
K. All water-soluble complete fertilizers (NPK) and commercial mixtures	
Solubility varies by product; consult label for directions for use.	

CHAPTER 8

Insect, Mite, Mollusc, and Vertebrate Scouting and Management

Arthropods in the strawberry planting can be beneficial (such as bees, spiders, and predatory mites); benign (such as green metallic beetles); or harmful (such as tarnished plant bugs). Harmful insects and mites attack the fruit, buds, leaves, and roots of the strawberry plant, and can also increase the susceptibility of damaged plants to other pests. A strawberry grower's objective should be to minimize damage from harmful insects while preserving beneficial insects.

This chapter is designed to familiarize growers with the biology of strawberry insects and mites, to help growers identify the damage pests cause, and to briefly outline ways growers can manage pests. Emphasis is on cultural controls since regulations and restrictions concerning pesticide use are continually changing and vary from state to state. Growers should consult their local Extension personnel for recommendations concerning the most effective management strategies for their area.

Bees

Scientific names: *Apis mellifera* and others

Wind and bees are responsible for pollinating the many ovules in a strawberry flower. Although the majority of pollination in strawberries can occur without bees, they can greatly enhance berry size and quality. Partially pollinated berries are small and tend to have a rough, dimpled, seedy appearance.

Many bee species are capable of pollinating strawberries, most of which occur in the wild. Of the managed bees, honeybees are most commonly used for pollinating strawberries. One or two strong hives per acre are sufficient to provide for the pollination needs of a strawberry field. A brood nestthat spans 5–6 frames is optimal.

Place hives off the ground, east-facing, in an area that receives maximum sunlight. Windbreaks near the hive are helpful. Do not allow grass to grow up around the hives and avoid spraying nearby fields with pesticides while the bees are present. Avoid using highly toxic pesticides within a week of introducing the bees (table 8-1). Before introducing the bees, mow the field to eliminate competing flowers and thus encourage the bees to visit the strawberries. Keep an ample supply of fresh water near the hive.

Some growers maintain areas near their fields exclusively for native and feral bees. The bees forage and nest in these sites and are available for the pollination needs of fruits and vegetables.

Table 8-1. Relative toxicity of pesticides to honeybees.

Chemical	Toxicity
Brigade (bifenthrin)	high
Captan	low
Dibrom (naled)	high
Kelthane (dicofol)	low
Lorsban (chlorpyrifos)	high
Malathion	high
Methoxychlor	low
Morestan (oxythioquinox)	low
Sevin (carbaryl)	high
Thiodan	medium
Thiram	low

Fruit Damage

Tarnished Plant Bug

Scientific name: *Lygus lineolaris*

The tarnished plant bug (TPB) is a small (¼ inch) bronze-colored insect with a triangular marking on its back (photos 8-1 and 8-2). The immature stage, or nymph, is smaller and bright green (photo 8-3). Superficially, TPB nymphs resemble aphids, but the nymphs have a more tapered body and longer legs and are much more active. TPB overwinters in the adult stage; nymphs are active in early spring and throughout the summer. Both adults and nymphs feed on the developing flowers and fruit, sucking out plant juices with straw-like mouth parts. Their feeding results in deformed fruit, typically referred to as "cat-faced" berries, "button" berries, or nubbins (photo 8-4). Cat-faced fruits are generally unmarketable.

Typically, 2–3 TPB generations occur per year, but the overwintering adults and the first spring generation of nymphs and adults are the most threatening to June-bearing strawberries. With day-neutral varieties, the situation becomes more difficult because the TPB population increases during the summer and continues to feed on flowers and developing berries as long as they are available.

Managing TPB is critical because crop losses from damage can reach as high as 90%. Controlling weeds in and around the plants may reduce populations of this insect. Weeds around the edges of the field should be mowed regularly to discourage the buildup of TPB. However, do not mow weeds while strawberries are in bloom, since this will encourage migration of the insects into the strawberry planting.

Begin sampling for TPB nymphs just before the bloom starts in the spring. Sample nymphs by tapping or shaking flower clusters over a white surface (white cardboard, paper plate or piece of plastic, for example). The shaking causes the nymphs to fall off the flower clusters and onto the white surface, where they can be seen and counted. At least 30 flower clusters should be sampled evenly across a field. If the average nymph count exceeds 0.25 nymphs per cluster before 10% bloom, or if more than 4 out of 30 clusters are infested with nymphs, then applying an insecticide is usually warranted.

Sample for nymphs at least once a week following a V-or X-shaped sampling pattern in the field (see figure 2-1). If no nymphs are found in the field until mid- to late bloom, then raise the threshold to 0.5 nymphs per flower cluster and make spray applications only after bloom is over; this protects bees and other pollinators. Early spray applications are preferable because they prevent buildup of TPB populations during bloom and avoid the spray residue left on fruit by late-season spray applications.

Strawberry Bud Weevil

Scientific name: *Anthonomus signatus* Say (Clipper)

The strawberry bud weevil, or "clipper," is an important pest of strawberries. It occurs somewhat less frequently than tarnished plant bug but can cause economic injury. This insect is a very small beetle (⅛–¼ inch) with a copper-colored body and a black head with a long snout (photo 8-5).

This insect overwinters as an adult in the soil or plant debris, either in the strawberry field or in nearby woods. In the spring the female weevil emerges from the over-wintering site and moves into fields. After locating a suitable host plant, she chews a small hole in unopened flower buds and lays an egg in the hole. She then girdles the stem just below the bud. The flower bud dries up and dangles from the stem, eventually falling to the ground (photo 8-6). The immature weevils, or grubs, develop in the girdled buds and pupate in the soil. There is only 1 generation per year.

Clippers may cause only minimal damage some years. To scout for clippers, begin examining the plants as soon as flower trusses are visible in the crown. Examine the plants at least once a week, looking for clipped buds or the presence of the adult weevil in the flower clusters. The insects find shelter among the clusters of buds, especially on cold days. A careful, very close inspection is usually necessary to ensure an accurate assessment of injury.

As with tarnished plant bug sampling, follow a V- or X-shaped sampling pattern (see figure 2-1) in the field, sampling at 5–10 locations. Additional samples may be taken along wooded edges of the field since the weevil migrates into the field from woods and hedgerows.

Photo 8-1. Tarnished plant bug adult (D. Handley).

Photo 8-4. Damage from tarnished plant bug called "cat-facing" or "button" berries (D. Handley).

Photo 8-2. Tarnished plant bug adult (D. Handley).

Photo 8-5. Strawberry clipper adult (D. Handley).

Photo 8-3. Tarnished plant bug nymph (D. Handley).

Photo 8-6. Strawberry clipper damage (D. Handley).

Examine a 2 foot section of row at each location. A sampling frame (a 2 foot square frame made of wood or other lightweight material) may be made for this purpose (photo 8-7).

Traditionally, 0.6 clipped buds per foot of row was used as the economic threshold. However, recent research has shown that many varieties can compensate for clipper damage by increasing the size of remaining berries and producing more flowers. Therefore, the threshold of 0.6 clipped buds per foot may be too low for most varieties; 5 clipped buds per foot of row is a more accurate threshold and will reduce the number of sprays recommended for this pest. In many cases, clippers cause negligible losses.

Clipper presence is usually concentrated at the edge of a field near woods, so a border application of insecticide (the first 5–10 rows) may be sufficient for control. Attempts to use rowcovers to exclude clippers have not been effective, presumably because some individuals will overwinter in the strawberry field and then emerge under the rowcover.

Spotted Wing Drosophila

Scientific name: *Drosophila suzukii*

Spotted wing drosophila (SWD) is a relatively new, invasive pest in the northeastern United States, originating in western Asia. They are small (⅛ inch) vinegar flies that attack most soft or thin-skinned fruits (photo 8-8). The female flies can insert eggs through the skin of ripening fruit. The larvae, or maggots, are small and translucent and feed on the flesh of fruits. Each female fly can lay between 300–400 eggs. The cycle from egg to larvae to pupae to adult is very short and can be completed in as little as 14–21 days. Even a relatively small influx of flies into a field can soon develop into a major infestation. Infested fruit may contain a few to many larvae and will prematurely soften and decay. Infested fruit will have very reduced shelf life, and larvae will be seen emerging from the remains (photo 8-9).

Although several insecticides are effective against the flies, keeping berries free from infestation can be difficult because of the near constant pressure of countless flies throughout the late summer and fall. To date, only frequent and repeated insecticide sprays through the ripening and harvest period have proven effective.

For June-bearing strawberries, SWD do not typically build up to populations high enough to cause significant damage until after harvest is complete.

Growers should be vigilant however, especially with later ripening varieties, and be ready to apply appropriate insecticides if flies are observed in the field or larvae are found in the fruit. For day-neutral strawberry varieties that ripen in the late summer and fall, SWD is a significant threat.

Homemade traps for the flies can be made by drilling ⅛ inch holes near the top rim of a plastic deli containers or cup (red or black color is most attractive) (photo 8-10). The cups should be baited with about 2 ounces of apple cider vinegar or sugar water with a pinch of yeast. Place the traps in or near the planting at the height of the plants in the shade. Commercial traps and baits are available and may be more convenient. Check the traps regularly for vinegar flies.

The males can be identified by a single small black spot near the top of each wing. The females have no spots. It is likely that by the time flies are found in the traps, eggs have already been laid in the fruit. Therefore, sprays would be recommended as a preventative measure on any fruit starting to ripen in late July to early August, depending on a farm's location (infestations tend to occur earlier in more southern locations). Weekly spray coverage may be adequate under low pressure, but twice weekly sprays may become necessary for high pest pressure in fall crops of day-neutral strawberries. Pay close attention to days-to-harvest requirements and limitations on number of applications per season on all product labels. Most insecticides will be made more effective by adding sugar to stimulate SWD feeding. On smaller plantings, placing a fine screen (less than 1 millimeter mesh) or row cover over the plants can effectively keep flies from laying eggs on fruit, but can interfere with pollination if flowers are still present.

Photo 8-7. Scouting for strawberry clipper using a square wood frame (D. Handley).

Photo 8-8. Spotted wing drosophila (D. Handley).

Photo 8-9. Spotted wing drosophila larvae found inside softened strawberry fruit (B. Sideman).

Photo 8-10. Homemade trap for spotted wing drosophila (D. Handley).

Photo 8-11. Strawberry sap beetle adult (R. Williams).

Photo 8-12. Strawberry sap beetle larva (R. Williams).

Field sanitation—removing all waste fruit from the field—can help reduce infestations. Carefully grade fruit before marketing, removing any soft berries which may contain larvae. Chilling harvested fruit to 32°F prior to marketing can significantly reduce emergence of larvae and prolong shelf life.

Strawberry Sap Beetle

Scientific name: *Stelidota geminata* Say

Sap beetles chew cavities into ripe fruit, very similar to slug injury. They can also spread fungal and bacterial organisms that cause fruit rot.

Adults are small, oval beetles about ¼ inch long and dark brown in color, with no prominent markings on their wing covers (photo 8-11). They are sometimes hard to see because they drop to the ground when disturbed. They are found primarily when there is ripe fruit in the field and can be seen in the cavities of chewed fruit. Larvae of strawberry sap beetle are small (photo 8-12) and develop in decomposing fruit.

The best management strategy for this pest is sanitation; keep the field as free of ripe fruit as possible. Trapping sap beetles with bait baskets of overripe fruit or bread dough placed between the borders of the field and wooded areas may help prevent beetles from infesting a field. Insecticide sprays can be effective but are not typically recommended during harvest because the risk of residue on ripe fruit is high. Preventing the problem by avoiding overripe fruit in the field is the best strategy. Early renovation of fields to eliminate food sources may reduce populations the following year.

Sap (Picnic) Beetle

Scientific name: *Glischrochilus quadrisignatus* Say

This beetle can cause significant damage to ripe strawberries but is not as common as strawberry sap beetle. Adults are about ¼ inch long and are black with 4 yellowish orange spots on their backs (photo 8-13). Over-wintering beetles emerge from under duff on the soil surface, usually after temperatures exceed 60–65˚F for several days. They feed, mate, and lay eggs in the duff. After larval and pupal development is completed, new adult beetles appear from July to September, and will feed on ripening strawberries. There are 2 generations per year.

The sap beetle, also called the "picnic beetle" because it can become a nuisance at any outdoor function where food is present, is attracted to ripe fruit or any fermenting material. From the start of fruit coloring through harvest, these small beetles may be found feeding on berries. They either feed near the surface or bore into the fruit, where they can be found next to the receptacle.

Because the beetles are attracted to injured and overripe fruit, control of other fruit-damaging pests and prompt harvesting of ripe berries can help reduce damage from this pest. Sprays should be applied, if necessary, as fruit begins to color or as soon as beetles become evident.

Flower Thrips

Scientific name: *Frankliniella tritici*

Flower thrips are very small insects, with the adults being a little more than a millimeter in length with yellowish, cigar-shaped bodies (photo 8-14). They are weak fliers, with fringed wings that allow them to be carried by the wind. The immature stages are wingless, but they can move very quickly around a plant, hiding in protected places. While flower thrips are probably not able to survive the winters in the Northeast outside of greenhouses, they can ride air currents from southern areas and arrive suddenly and in high numbers if conditions are right. These insects feed by piercing plant tissues and sucking up the resulting sap. They prefer to feed on flower parts but will move on to leaf and other tissues when the populations are high. Thrips have a rapid generation cycle; once in a field, populations can build quickly.

Affected plants look generally healthy, but affected berries are small and hard, with a "seedy" appearance. Cracking may occur on the berries, along with a bronze discoloration (photo 8-15).

Slugs

Scientific name: Various

Slugs are dark gray, black, yellow, or brown wormlike mollusks. They may be covered with spots and range in size from 1½–7 inches long. Slugs can be common pests of vegetables, field crops, and ornamentals throughout the United States and Canada. High populations of slugs are often found during a wet spring when the preceding winter was mild, especially in heavily mulched fields.

A slug is often described as a snail without a shell. The head of the slug has two sets of tentacles. The eyes are on the tips of the upper tentacles. The lower tentacles, which are shorter, are used for tasting and smelling. The mouth is located between and below the lower tentacles and is equipped with a radula, a tooth-covered rasp that the slug uses to grate plant tissue. The slug glides along a path of mucus that is secreted by the pedal gland located just below the mouth.

Slugs mate throughout the warm months of the year. They are hermaphroditic, meaning that an individual slug has both male and female reproductive organs. Certain species may even self-fertilize, which means they can produce viable offspring without mating. After mating, clusters of 8–60 clear jellylike eggs are laid in sheltered areas on the ground. Newly hatched slugs resemble the adults but are much smaller. The average life span of the slug is from 9–13 months, and an adult can lay from 300–500 eggs during its lifetime.

Because the eggs are very resistant to cold and drying, they are often the only life stage to overwinter. However, adults may also survive mild winters where they are well sheltered.

Slugs chew holes of various sizes in strawberry fruit (photo 8-16). Because slugs often feed at night, the only evidence of their presence may be glistening patches or streaks of dried slime seen on the plants and the ground nearby.

Slugs exhibit homing behavior and a tendency to aggregate. They will return to a secure hiding place night after night and will also seek out other slugs. Using traps can help determine the level of slugs in a field.

Dig holes 4 inches in diameter and 6 inches deep and cover them with asphalt shingles wrapped in aluminum foil to keep the hole dark, cold, and moist. Placing a shallow dish containing beer at the bottom of the hole will act as an attractant. Check the traps in the early morning. The traps may offer some control on a small scale, but slug damage can be high when large numbers of slugs are present. Applying treated slug baits in and around the field in the fall and early spring can provide good control. Unfortunately, the straw mulch used for winter protection and disease and weed suppression may also encourage slugs. Slug populations are often highest in fields that were in sod the previous year or that had crop debris on the ground. If strawberries are to be planted following sod, it is best to plow the field early in the year before planting.

Birds

Scientific names: Various

Birds are often the first "customers" into a strawberry field when the fruit begin to ripen. While many growers do not experience significant problems with birds, they can destroy meaningful amounts of early-ripening fruit. Cedar waxwings, robins, mockingbirds, and seagulls are the major problem species and are difficult to discourage. Cedar waxwings descend on strawberry fields in flocks from roosting sites in trees and peck large holes in the fruit (photo 8-17).

Birds are quite docile and will remain in the field despite the presence of humans. Maintaining a near constant presence in the field and eliminating roosting sites will reduce the damage caused by these birds. Audio and visual scare devices can be effective if their location in the field is frequently changed.

Photo 8-13. Sap beetle (also known as the "picnic beetle") adult (NYSAES).

Photo 8-16. Slug damage (S. Willden).

Photo 8-14. Thrips closeup on strawberry fruit (K. Demchak).

Photo 8-17. Bird damage to fruit (B. Sideman).

Photo 8-15. Thrips damage to fruit (B. Sideman).

Photo 8-18. Bird cannon in a plasticulture planting (D. Handley).

Cannons and screamers are effective for short periods of time but can be very bothersome to neighbors and customers because of their repetitive nature (photo 8-18). Computer-generated species-specific bird distress calls coupled with moving hawk models, can be effective for more than a week at a time. Inflatable tube "air dancers" may also be good visual deterrents. Netting can also be an effective strategy to exclude birds (photo 8-19), but it requires regular removal for harvest and reapplication. Cedar waxwings and robins are songbirds protected by law and may not be killed without permits from state and federal authorities.

Leaf Damage

Strawberry Leaf Roller

Scientific name: *Ancylis comptana fragariae*

The immature stage of this insect (the larvae) feeds on strawberry leaves. The larvae are small green or bronze caterpillars up to ½ inch long at maturity (photos 8-20 and 8-21). They occur in the field prior to bloom and in mid- to late July. Larvae are first found on the undersides of leaves in silken covers, then on upper sides of leaves that have been folded or rolled and tied with silken threads.

To control this pest, remove and destroy rolled leaves. If infestation is severe, a pre- or post-bloom insecticide application may be needed. Timing will depend upon when larvae are present; often a pre-bloom spray is recommended.

Two-Spotted Spider Mite

Scientific name: *Tetranychus urticae*

Two-spotted spider mites (TSSM) are very small (1⁄50 inch) insect-like creatures that feed on strawberry foliage (photos 8-22 and 8-23). Under heavy infestations, mite feeding destroys leaf chlorophyll and causes leaves to turn bronze (photo 8-24). Yield reductions may occur due to the weakened state of the plants.

TSSM are usually found on the undersides of leaves; are barely visible to the naked eye; and are especially active during hot, dry months. TSSM overwinters in the adult female stage. In the spring or early summer, females lay unfertilized eggs, which hatch into males, and fertilized eggs, which hatch into females, at a rate of 2 to 6 per day, depending on temperature. A female can live 60–70 days. Mites generally form colonies and may be most noticeable by the webbing that they produce in the vicinity of the colonies. These colonies are usually localized in "hot-spots" in the field rather than being evenly distributed throughout the field.

Symptoms of mite damage include yellow stippling, bronzing, and curling downward of leaves, especially older ones. Webbing may be visible on undersides of leaves.

Sample mites weekly using a V or X-pattern through the field (see figure 2-1) with 5–10 sample locations. Sample 5 leaves at each location, in order to obtain a 60-leaf sample. Examine the undersides of the leaves with a hand lens for the presence or absence of mites. If 15 or more leaves have mites present (25% infested) a miticide spray should be applied to prevent significant damage to the plants. Record the information on a field map so that "hot-spots" can be identified and treated. Several miticides are registered for use on TSSM in strawberries, and their use may be necessary with large populations. Some growers use miticides as the initial "knock down" agent, then release predators 7–10 days later for continued control. When spraying for mites, make sure to get good coverage on the undersides of leaves by using high pressure and high gallonage (200 gal/acre at 100 lbs/in^2).

There is a native predator in the Northeast that feeds on two-spotted spider mite. This predator, *Amblyseius fallacis* (also a mite), is equally small but has a big appetite. It can be distinguished from TSSM because it lacks the two spots on its back and is teardrop shaped, shiny, and pale yellow in color (photo 8-25). In addition, *A. fallacis* moves rapidly across a leaf as it reaches for prey. Two-spotted mites generally move slowly across the leaf. When sampling a field, note the presence of both predators and TSSM. Fields with lots of predatory mites should not be sprayed.

Several companies now commercially produce predatory mites that feed on spider mites, including *A.fallacis*. These predators can be released

Photo 8-19. Netting for bird exclusion (B. Sideman).

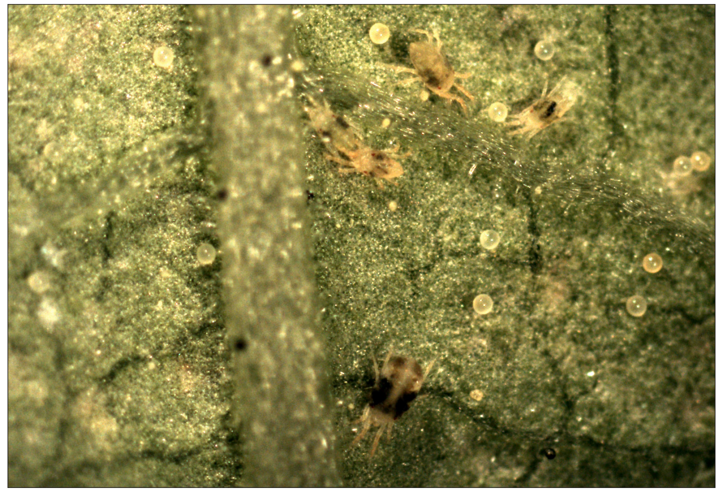


Photo 8-22. Two-spotted spider mites and eggs (S. Willden).

Photo 8-20. Strawberry leaf roller (K. Demchak).

Photo 8-23. Two-spotted spider mites on the underside of a leaf (D. Handley).

Photo 8-21. Strawberry leaf roller (K. Demchak).

Photo 8-24. Two-spotted spider mites effect on upper-side of leaves (S. Willden).

at a lower threshold than one would apply a pesticide, as it takes more time for them to disperse and have an impact. It is also important to encourage natural enemies of spider mites by reducing the use of pesticides that harm natural enemies (table 8-2). High nitrogen fertilizer rates also encourage mites to build up in the planting.

Table 8-2. Relative toxicity of pesticides to beneficial mites.

Chemical	Toxicity
Brigade (bifenthrin)	high
Captan	low
Lorsban (chlorpyrifos)	medium
Sevin (carbaryl)	high
Vendex (hexakis)	low

Cyclamen Mite

Scientific name: *Phytonemus pallidus*

The cyclamen mite is primarily a greenhouse pest but also causes serious losses in strawberry plantings. This tiny mite (¼ mm long) is scarcely visible to the unaided eye (photo 8-26); even the adults are visible only with a good hand lens or microscope. Mature cyclamen mites are soft-bodied, pinkish orange in color, and shiny. The hind legs are threadlike or whiplike in the female and grasping or pincerlike in the male. Eggs are translucent, comparatively large, and often so abundant that they appear as a white mass along the midveins of the folded leaves. The immature stages, an active larva and immobile nymph, are translucent white.

Adult females survive the winter in protected areas in and around the crowns of strawberry plants. In early spring, when the plants begin to grow, the mites start reproducing. Most females move to the young, folded leaves to lay their eggs; as each leaf begins to open, the females move down to the next developing leaf bud. The eggs and immature stages are thus protected within the folded leaves. The folded strawberry leaves also provide the high humidity that cyclamen mites require.

Under favorable conditions, each female lays about 90 eggs, about 80% of which develop into females. The mites can grow from eggs to adulthood within two weeks. In warm climates, they keep multiplying throughout the spring, summer, and fall. Because they mature so quickly and have such a long egg-laying period, all stages of development are present throughout the period of reproduction, and populations can increase very rapidly under favorable conditions. Cool weather greatly reduces reproduction, and by early fall most of the females are hibernating around the crown of the plant. Two peaks of reproduction occur, the largest in early June during harvest and a smaller peak near the end of September.

Cyclamen mite feeding on young, unfolding leaves in the crown of the plant causes the mature leaves to appear stunted, crinkled, purplish, and malformed when they emerge (photo 8-27). The first obvious symptoms of cyclamen mite feeding are a slight retardation of growth and somewhat roughened, off-color leaves. The leaves soon become crinkled and the stems do not elongate, so the plants take on a characteristic flat appearance and the flower buds fail to open.

When infestations become very high, the new leaves are severely stunted and crinkled and form a more or less compact mass in the center of the plant. At this time, the leaves are usually brownish green. When leaf infestations become too heavy, the mites move out to feed on the flowers, causing them to wither and die. Fruits on infested plants are small, dry, and distorted, and the seeds stand out on the flesh of the berry in a characteristic manner. Just a few mites per leaf may reduce plant productivity significantly.

Cyclamen mites can be very difficult to control with pesticide sprays because of their high rate of reproduction and inaccessibility within the strawberry plant. Some success has been achieved with hot water dips of plants prior to planting and with systemic miticides. Miticides may be most effective when applied during bed renovation (when rows are narrowed and leaves mown off) than when applied while the leaf canopy is present. Spray volume (200 gal/acre) and pressure (100 lbs/in^2) must be high for the material to contact the mites. Some predatory mites, if managed properly, may effectively reduce cyclamen mite populations.

Establishing new plantings with mite-free nursery stock and isolating new plantings from old ones are important steps for preventing cyclamen mite infestations. The mites can also be carried from one point to another on farm implements, clothing, or plants.

Aphids

Scientific name: *Chaetosiphon – C. fragaefolii, C. thomasi, and C. minor*

Strawberry aphids are soft-bodied insects. The adults are less than 1⁄16 inch long, and winged and wingless adult females may be present at the same time. The wingless form is pale green or yellowish. The winged form is light green with black markings. Species of *Chaetosiphon* are distinguishable by the number and arrangement of knobbed dorsal abdominal setae. At least 1 aphid species occurs in every strawberry growing area. In Ohio, *C. minor* and *C. thomasi* are most important, whereas in most other areas from California to New England, *C. fragaefolii* and *C. thomasi* are most common.

Several generations of aphids occur in a season. Aphid reproduction is favored by cool, damp conditions. The development of winged aphids peaks in spring (March through June) and in fall (September to November), allowing the spread of the colonies throughout the fields and beyond.

Aphids are usually found on new shoots and buds in the crown of the plant and along the veins on the undersides of leaves (photos 8-28, 8-29, and 8-30). They move slowly and typically remain motionless when a plant is being examined. *Chaetosiphon* species feed exclusively on leaves and petioles, sucking out plant juices. When present in large numbers, they weaken the plant. In the process of feeding, they excrete large quantities of waste in the form of "honeydew", on which sooty mold grows. Although not very harmful to the plant, sooty mold can make picking difficult and render the fruit un-marketable.

The purpose of aphid control, generally, is to manage the spread of aphid-vectored virus diseases. Aphids can be controlled with several insecticides. However, the decision to use an insecticide and the selection of a particular insecticide depends on several factors: the time of application (planting time, before harvest, after harvest); aphid resistance to insecticides; the problem to be controlled (aphid injury or virus transmission); and the presence of other pests and predators. Many pesticides effective against aphids are also toxic to predators (photo 8-31); such pesticides should be used only when aphid infestation is severe.

Potato Leafhopper

Scientific name: *Empoasca fabae*

The potato leafhopper occurs throughout eastern North America and may reduce plant growth and runner production in commercial plantings of susceptible strawberry varieties. Adults and nymphs feed along the veins on the undersides of leaves by sucking up plant juices. During the feeding process, they inject a toxic substance with their saliva that causes plugs to form in the vascular system of the plant. The affected leaves develop yellow streaking and distortion, symptoms often mistaken for herbicide injury or nutrient deficiency (photo 8-32).

The adult leafhopper is bright green and about 1⁄8 inch long. It takes flight quickly when disturbed, so sweep-nets are used to catch and identify them. Young nymphs are smaller and light green and are easily identified by their habit of moving sideways when disturbed (photo 8-33). Females deposit eggs within leaves and stems of plants, and nymphs develop on the undersides of leaves. Nymph activity is greatest from late spring to midsummer. Adult leafhoppers are highly mobile, migrating from the southern to northern states each year. The wide host range of this insect, nearly 140 plant species, facilitates the annual migration. Leafhoppers can usually be adequately managed with several available insecticides. Thorough coverage of the foliage, including the leaf undersides is needed for good control.

Spittlebug

Scientific name: *Philaenus spumarius*

Spittlebug is a pest of strawberries throughout North America and Europe. It is present in most of the United States east of the Mississippi River and along the Pacific coast; but it is most problematic

Photo 8-25. Beneficial predatory mite (J. Nyrop).

Photo 8-28. Winged mother and unwinged young aphids (unidentified species), alongside shedded white skins and oval white syrphid fly eggs (A. Eaton).

Photo 8-26. Cyclamen mite (NYSAES).

Photo 8-29. Aphids (unidentified species) and shedded white skins on a young strawberry plant (K. Orde).

Photo 8-27. Cyclamen mite damage (D. Handley).

Photo 8-30. Aphids (unidentified species) on the underside of a lettuce leaf (A. Eaton).

in areas of high relative humidity, such as the northeastern United States and Oregon. Spittlebugs feed on more than 400 species of agricultural plants. They get their name from the frothy spittle they produce as nymphs to protect themselves (photo 8-34).

Adult spittlebugs resemble leafhoppers. When newly emerged, the adults are bright green, but later turn dull brown or mottled gray; they are about ¼ inch long (photo 8-35). Adults are present on vegetation from late May or June until freezing occurs in the fall. There is only 1 generation per year. Eggs are yellowish and about 1⁄16 inch long, and may be laid as early as July, but the peak egg-laying occurs during September and October. Spittlebugs overwinter as eggs inside the lower parts of the strawberry plant in rows of 2–30. Newly hatched nymphs appear from April to May and are whitish to bright yellow or orange, later turning green. At 10% bloom of strawberries, they are quite small—about the size of a pinhead—and later may reach a length of ¼ inch. They produce a protective frothy spittle mass over their bodies which can be about ½–1 inch in diameter. Nymphs remain inside the spittle until they transform into adults, 5–8 weeks after the eggs hatch.

The nymphs pierce the plant stems and suck plant juices. Initially, they feed at the bases of plants, but later they move up into the developing tender foliage. This feeding can cause distorted leaves and stunted berry growth. The crinkled and dark green appearance of the leaves can resemble leaves affected by crinkle virus, but spittlebug injury is not viral; plants recover after the spittlebug departs.

Spittlebugs have always been considered a problem in pick-your-own operations, because their spittle annoys the strawberry pickers. However, spittlebugs rarely become a large enough problem to cause significant yield loss.

Begin to estimate spittle mass density at 10% bloom. Randomly inspect 5–10 one-square-foot areas per acre of strawberry plants at 2 week intervals. On hot, dry days, the nymphs and their spittle may be at the base of the plant, so it will be necessary to spread the plants and inspect the crowns and soil surface. On warm and humid or rainy days, the spittle masses can usually be seen on the surfaces of leaves and stems. Young nymphs will be small and orange; nymphs at later stages will be as long as ¼ inch and orange to green in color. Populations are usually largest in weedy fields. A threshold of two bugs per square foot may warrant treatment.

Cutworms

Scientific name: Various

The immature stage (larvae) of these insects causes feeding injury to plants. Larvae may reach two inches long at maturity (photo 8-36). The color and arrangement of stripes and spots varies from one kind of cutworm to another. Cutworms may be observed on plants at night during spring and summer. Larvae consume leaves, buds, and developing fruits. Options for control vary considerably from state to state.

Root Damage

Strawberry Rootworm

Scientific name: *Paria fragariae*

The adult form of this insect is a small (⅛ inch) beetle that is round and copper-colored with dark markings on its back (photos 8-37 and 8-38). The immature root-feeding grubs are also small (⅛ inch) and creamy white in color with 3 pairs of legs. They actively feed on roots in the late spring to early summer. The new generation of adults appears after renovation (late July or early August).

This insect can be observed most easily in the field as adult beetles feeding on leaves. Feeding occurs at two times in the growing season; May (by overwintering adults) and July through August). This feeding creates shot holes in the leaves. The second feeding period is usually more evident because a greater number of beetles are feeding.

As with all root-feeding insects, control of the root-feeding stage is very difficult. Therefore, control measures for strawberry rootworm should be directed toward the adult stage of the insect. The presence of adults can be detected by observation of the feeding injury or direct sightings of the adult beetles in the field. Sticky traps may aid in sighting strawberry rootworm adults since they feed primarily at night.

Photo 8-31. Ladybird beetle larva—a predator of aphids (K. Orde).

Photo 8-34. Spittlebug mass and nymphs (R. Williams).

Photo 8-32. Leafhopper discoloration on foliage (K. Orde).

Photo 8-35. Spittlebug adult on fruit (NYSAES).

Photo 8-33. Leafhoppers on the underside of a leaf (K. Orde).

Photo 8-36. Cutworms (B. Sideman).

If feeding injury is observed in May or June, an insecticide spray at this time will reduce the number of egg-laying females and, therefore, the number of grubs feeding during the summer. When the next generation of adults emerges in July or August, control measures may be needed again.

No threshold is established for this insect. Feeding injury is usually most damaging if root diseases (such as black root rot) infect the plants as a result of wounding. Therefore, it is advisable to keep the root-feeding population low.

Root Weevils

Scientific name: *Otiorhynchus spp.*

There are more than 20 species of root weevils that attack strawberries in the United States. In the Northeast, the 3 major species are the black vine weevil, *Otiorhynchus sulcatus* (Fabricius); the strawberry root weevil, *O. ovatus* L.; and the rough strawberry weevil, *O. rugostriatus* Goeze.

The root weevil adult is a brown to black beetle, with rows of pits or punctures along its back (photo 8-39). Like other weevils, its mouth parts are extended into a snout. The 3 species discussed here look similar but differ in size. The strawberry root weevil is the smallest in size, about ⅕ inch and black to light brown; the rough strawberry weevil is generally an even chocolate brown and ¼ inch long; and the black vine weevil sometimes as small flecks of yellow on its black body and can reach ⅖ inch in length.

Adults of *Otiorhynchus* generally emerge in late May through June from pupae in the soil. They feed at night on foliage and hide during the day. The adults are unable to fly, so they must travel through the field on foot. After a period of approximately 30–60 days (for the black vine weevil) or 10–14 days (for other species), they begin to lay eggs. Some of the larvae do not pupate in the spring and will remain in the soil throughout the summer. They then pupate in the fall and overwinter as adults, to emerge the following spring.

Depending on the species, peak egg laying occurs from late July through August. Eggs are laid in the soil around the plants; they are pearly white when laid but soon change to an amber color. Eggs of the strawberry root weevil are 1⁄50 inch long, and those of the black vine weevil are 3⁄100 inch spheres. Larvae, or "grubs," are creamy white or dirty white to brown, have no legs, and lie in a characteristic "C" position in the soil (photo 8-40). Grubs of the strawberry root weevil are about ¼ inch long when fully grown; those of the black vine weevil are ½ inch long. By October, most of the eggs have hatched into larvae; hatching occurs about 10 days after the eggs are laid. Young larvae feed on fine roots and bark in mid-summer, overwinter in the soil, and cause their heaviest damage in the spring. Black vine weevil pupae are soft and white. Adults emerge after a short pupation period in April, May, or June, depending on the species and site. Only one generation occurs per year.

Adult root weevils eat notches in the leaves, but this damage is seldom important (photo 8-41). The larvae cause serious damage by tunneling in the roots and crowns as they feed. Most of the damage is caused by the later instars of larvae during March and April that eat the fine roots and burrow into crowns. Evidence of feeding is a reddish-brown sawdust-like frass surrounding the crown (photo 8-42). Plants wilt, become stunted, and may eventually collapse under the stress of fruiting or hot weather.

Heavily damaged areas in the field can be large—sometimes up to 1 acre—and circular, because of the beetles' behavior of gathering in groups. Without control, damage can be so severe by the second fruiting year that early termination of the planting is necessary. Newly transplanted strawberry plants can be particularly susceptible to black vine weevils.

Parasitic nematodes have been used effectively on black vine weevil larvae in cranberries but have had only limited success in strawberries. Larvae are also attacked by some general predatory insects including carabid and staphylimid beetles. Some plant resistance has been noted in strawberry clones, but this has not yet been incorporated into commercially acceptable varieties.

Photo 8-37. Strawberry rootworm adult (D. Handley).

Photo 8-38. Strawberry rootworm adult (D. Handley).

Photo 8-39. Black vine root weevil (D. Handley).

Photo 8-40. Root weevil larva (D. Handley).

Photo 8-41. Root weevil notching (L. McDermott).

Photo 8-42. Root weevil damage to planting (L. McDermott).

No economic thresholds have been established for root weevils, but 2–8 black vine weevils per plant are known to cause economic damage. Soil fumigation provides effective preplant control of larvae. Chemical applications to the soil following bed renovation can reduce populations. Postharvest foliar sprays to control the adult beetles during the summer are a more common treatment. Applications should be delayed until as many adults as possible have emerged, but before egg laying begins. To prevent the migration of insects to other beds, plow under old, infested beds as soon as possible. Rotate fields to an unsuitable host (for example, corn or pumpkins) for at least two years. This will destroy a large number of adult weevils, since these pests do not fly. Keep new beds far from infested sites and clean farm equipment before moving from infested fields to new fields to prevent spreading the pests.

White Grubs

(Japanese Beetle, Oriental Beetle, Rose Chafer, Asiatic Garden Beetle, June Beetle)

Scientific name: *Popilla japonica, Anomala orientalis, Macrodactylus sub-spinous, Autoserica castanea, and Cotinia nitida*

White grubs cause root damage to strawberries that weakens the plants and also provides entry sites for root diseases. Adult stages may also cause leaf damage.

The **Japanese beetle** is metallic brown/green in color (photo 8-43) and the **oriental beetle** ranges from black to mottled black and brown, and even pale brown (photo 8-44). Both are approximately ½ inch long and often found feeding in small groups on leaves. The beetle overwinters as a larva in the soil, pupates in the spring and emerges in July. The adult **rose chafer** (photo 8-45) is longer than the Japanese beetle, with a reddish-brown head. The body is covered with yellow hairs, giving it a muted yellow appearance. This beetle is nearly 1 inch long and ½ inch across with flattened margins. **Asiatic garden beetles** are small (⅜ inch) and velvety cinnamon-brown color. **June beetles** are a robust 1 ½ inch long and shiny dark brown in color (photo 8-46). All of these beetles have wide host ranges, although some feed more heavily in strawberries than others.

Photo 8-43. Japanese beetle adult (B. Sideman).

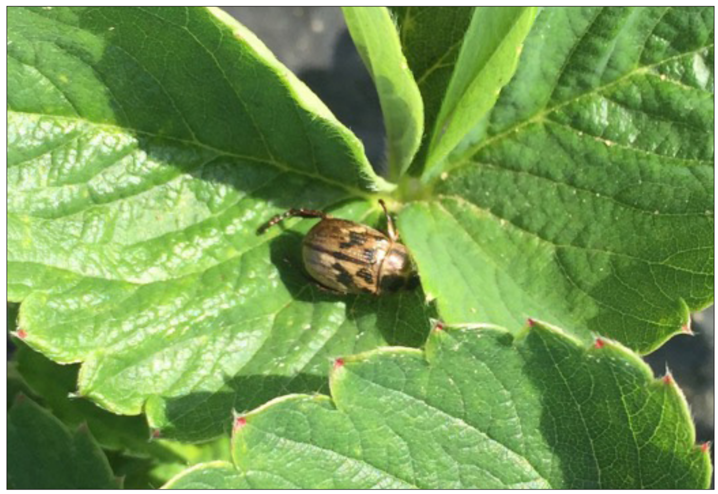


Photo 8-44. Oriental Beetle adult (K. Orde).

Photo 8-45. Rose chafer adult (NYSAES).

The larvae (or grubs) of these insects look quite similar to one another and are generally referred to as white grubs (photo 8-47). They are C-shaped, have 3 sets of legs, and are up to 1 inch long. They are distinguishable from the larvae of root weevils, which are smaller (about ¼ inch long) and have no legs. They are very difficult to manage after a strawberry bed has been planted.

As adults, the beetles feed on the leaves, "skeletonizing" them, i.e., leaving just the veins. Leaf feeding typically occurs in late July through mid-August. It is unclear how much damage is tolerable. Losses of 25% of foliage have been observed without significant impact on the crop. Severe defoliation, however, can inhibit initiation of flower buds in the fall, reducing next season's yield. Also, adult beetles lay eggs in the soil at the base of plants, which hatch into larvae, feed on the roots and burrow into the base of the crown of strawberry plants and overwinter in the soil.

Management of grubs in the soil can be very difficult. Soil insecticide drenches can be effective if applied at the appropriate time; usually late summer to early-fall when eggs hatch into grubs, and the grubs are feeding on plant roots. Soil insecticides must be applied before the grubs burrow deeper into the soil for overwintering and are more effective when grubs are young.

Adults can also be targeted with appropriate insecticides when they appear the in spring and early summer. Traps that use pheromone and feed lures (specifically for Japanese beetle) are commercially available and, while quite effective at catching beetles, have not proven to offer effective control, as the traps often attract more beetles to the area.

Milky spore disease is a commercially available bacterium that can be incorporated into the ground to infect and kill grubs for many years. Several formulations are on the market. However, it is difficult to get the bacteria established in northern soils, and results have been inconsistent. Therefore, milky spore is not considered a reliable control measure in this region.

Pre-establishment practices that should be followed to decrease the risk of white grub problems include avoiding planting into newly turned sod land; rather, plow the field and let it lie fallow or plant a rotational cover crop such as sudangrass, buckwheat, pumpkins, or squash for at least one season prior to planting strawberries. Avoid siting a strawberry field next to grassy fields, which are often a harbor of these beetles and their larvae.

Photo 8-46. June beetle adult and larva (J. Dill).

Photo 8-47. Oriental Beetle grub (D. Handley).

Further Reading & Citations

Cooley, D. R. and S. G. Schloemann. Integrated Pest Management for Strawberries in the Northeastern United States. University of Massachusetts Cooperative Extension Bulletin C211.

Maas, J. L. Compendium of Strawberry Diseases.2nd Edition St. Paul, Minnesota: American Phytopathological Society, 1998.

Williams, R. N. and W. R. W. Rings. Insect Pests of Strawberries in Ohio. OARDC Research Bulletin 1122. Ohio Agricultural Research and Development Center, Ohio State University, 1980.

CHAPTER 9

Disease Management and Physiological Disorders

The majority of plant diseases are caused by fungal organisms but bacteria, viruses, phytoplasmas and nematodes also cause disease. Fungal organisms are ubiquitous in strawberry plantings and most are beneficial. They help with decomposition of dead plant material, make nutrients available, and some compete with harmful fungi to keep their populations low. However, a small number of pathogens are extremely harmful to strawberries. Below are descriptions of those diseases commonly found in strawberry production.

Fruit Damage

Sunscald

Sunscald is not caused by a pathogen, although the symptoms are often mistaken for a disease. Sunscald results from the outer fruit cells dying due to direct exposure to intense ultraviolet sunlight on hot days. Affected fruit exhibit light gray to brownish wet patches on the exposed side (photo 9-1). These patches will dry to form sunken tan lesions, and fungal organisms may invade the damaged tissue, causing it to turn black. Varieties that tend to have a lot of exposed fruit—that is, fruit not shaded by leaves—tend to experience more sunscald injury.

Evaporative cooling of plants with overhead irrigation has been suggested to prevent sunscald, but its effectiveness has not been demonstrated.

Rain and Hail

Precipitation in the form of rain (photo 9-2) or hail (photo 9-3) can damage or puncture fruit, rendering them unmarketable or make them susceptible to infection. In plasticulture, having the center of the bed “crowned” (i.e., higher than the edges) will help to shed water, reducing the likelihood that fruit sit in a pool of water. Growing plants under a protective structure is the best way to exclude precipitation altogether (Chapter 4).

Gray Mold

Scientific name: *Botrytis spp.*

Gray mold is one of the most important diseases of strawberry flowers and fruit. The fungus can be brought into a field if the nursery stock is infected or by spores being blown in from another infected area. Once established in a field, *Botrytis* produces an overwintering structure called sclerotia that aids in survival through the winter and is one way this disease can cause problems from one year to the next.

Symptoms on fruit start as small, firm light-brown lesions and that expand to cover the fruit in a gray fuzzy mass of spores (photo 9-4) that gives the disease its name.

During periods of wet or foggy weather in the spring, the fungus produces thousands to millions of spores on each infected leaf. These spores are then spread throughout the planting by wind and moving air currents and infect open strawberry flowers during rain and fog periods. Temperatures of 59–77˚F are ideal for infection, although infections are also common at lower temperatures when the weather is persistently wet.

Most gray mold infections occur during bloom, resulting in the development of symptoms on fruit during ripening. Although symptoms may become visible on green berries, typically at the stem end (photo 9-5) or if the fruit is in direct contact with other infected fruit. Fruit infection is accelerated by prolonged periods of favorable temperatures and high humidity within the fruiting canopy or in storage. If fungal spores germinate on improperly stored fruit that is allowed to become wet, the fruit will also rot.

Photo 9-1. Sunscald on fruit (K. Orde).

Photo 9-2. Water damage on fruit from sitting in a pool of water on a plasticulture bed (K. Orde).

Photo 9-3. Hail during strawberry harvest (A. Orde).

Photo 9-4. Later stage of gray mold on fruit (D. Handley).

Photo 9-5. Early stage of gray mold on fruit (K. Demchak).

Photo 9-6. Leather rot (W. Wilcox).

Botrytis spp. fungus require prolonged periods of high humidity and wetness to produce spores, infect blossoms, and develop in the berries. The key is to use cultural practices that promote good air circulation and rapid drying within the fruiting canopy. Selecting a proper site, practicing good weed control, and avoiding excessively wide plant rows are all important for minimizing losses from this disease. Avoid practices that promote lush plant growth (for example, applying excessive nitrogen or overhead irrigation water) since these also promote gray mold development. Research in New York has consistently demonstrated that supplying extra nitrogen in the spring (that is, in addition to the nitrogen commonly applied at renovation) increases the number of infected berries by approximately 300–500%. This risk should be considered with respect to any perceived benefits of such practices.

Strawberry varieties differ in their susceptibility to gray mold, although none are completely resistant. This means fungicide treatments are important for management of this disease. Fungicide treatments should focus on the bloom period since this is when fruit infections occur. The amount of protection needed depends on how conducive the weather is to this disease. One to three applications of a fungicide during bloom generally provide excellent control, although some growers obtain acceptable results with good cultural practices alone, particularly in dry years. Additional fungicide sprays after bloom seldom provide additional control of gray mold, although they may help control other diseases under wet conditions.

Resistance to fungicides is well known for this pathogen, so fungicides should only be employed when there are favorable conditions for the disease. The use of multisite fungicides and rotation between classes should be practiced.

Leather Rot

Scientific name: *Phytophthora cactorum*

Leather rot occurs sporadically in northern growing areas, but it can cause serious economic losses due to the off-flavors it causes in fruit. It is more commonly found in southern and midwestern states than in the Northeast.

The leather rot fungus is a soil-borne pathogen that produces its infectious spores when water becomes puddled due to excessive rainfall or irrigation. The spores can swim to fruit lying on the puddled ground and infect fruit in the plant canopy when contaminated soil or water is splashed onto them. Once initial infections occur, the leather rot fungus produces a different type of spore within the diseased berries that requires just a couple of hours of rain, fog, or dew at temperatures in the optimal range of approximately 60–80˚F. Once leather rot gets started in the field, disease incidence can explode in just 5 days if weather conditions remain favorable to the pest.

Fruit may become infected at any time during their development. Infected portions of green fruit turn brown but remain firm (photo 9-6), and the infection quickly expands until the entire fruit (inside and out) becomes dark and leathery in texture. They may be covered with white fungal growth following periods of wet weather or if they are incubated for 1 or 2 days at room temperature in a plastic bag with a damp paper towel. Infected mature berries are often inconspicuous but may have a dull pink to a lavender or purplish color. Such fruit generally has a sharp, pungent smell that is easiest to detect when cut open. They also have an intensely bitter, offensive taste that is easily imparted to jams or other products made from them. Both green and mature fruit eventually dry and form hard shriveled mummies, which can serve as a source of infection the following year in perennial systems.

Since the initial infection occurs when the infective spore swims or splashes onto the fruit, any cultural practices that inhibit this process are the first and most important line of defense. Establishing a thick layer of mulch between the soil and the fruit significantly reduces leather rot development.

Choosing planting sites with good soil drainage and minimizing soil compaction and rutting from equipment operation will reduce puddle formation and thus the production of infectious spores. This also helps protect against infection by the red stele fungus, which is related. Practices that promote good air circulation and rapid drying within the canopy will also help limit disease spread. Biological fungicides provide an additional measure of protection at planting as a preplant dip or in-furrow application, but they are most effective when used in combination with appropriate cultural practices. Many fungicides used for control of gray mold and other strawberry diseases are ineffective against leather rot; check for current recommendations.

Anthracnose

Scientific name: *Colletotrichum acutatum*

Anthracnose favors wet, warm conditions (77–86˚F, causing it to be more troublesome with day-neutral strawberry varieties. June-bearers can sustain significant losses, however, if weather conditions are favorable. Outbreaks of anthracnose are sporadic in the North but have become much more frequent since the mid-1980s.

This disease can be introduced to a field by planting asymptomatic nursery plants which can then further spread to non-infected plants. When the disease progresses, flower blight and fruit rot are the most common symptoms of the disease. Symptoms of flower blight include brown lesions on petals. The fruit rot can infect both green and ripe fruit. The primary symptom is 1 or more slightly sunken brown to black circular spots (lesions) about ⅛–½ inches in diameter. Lesions can develop anywhere on the fruit surface (photo 9-7).

In ideal conditions for the disease, a thin, glistening layer of creamy pink to salmon-colored spores can form in the centers of these lesions. If conditions are dry or if secondary organisms do not invade and cause soft rot, the fruit may become mummified and black. The anthracnose fungi may also attack stolons, petioles, leaves, crowns, and roots. Undergrown infections are often associated with stunting, wilting, and, in some cases, the collapse of plants in the field. However, fruit infections are a much more common cause of economic loss.

Their slimy, pink spores are produced during periods of high humidity and warm temperatures and are spread to the fruit by splashing and wind-driven rain. Once infection occurs, additional spore masses are produced within the sunken lesions. Spores can be spread to healthy fruit by additional rains, causing new infections and an epidemic if favorable weather conditions persist.

Strawberry anthracnose, once in the field, can only be managed by fungicides. The anthracnose fungi can only survive on plant residues for a limited time, and in Florida, it has been shown that it doesn't persist from one season to the next. Thus, the primary source of infection is the introduction of diseased plant stock. To reduce the chance of introduction, purchase dormant or plug plants from reputable sources only. For plug plants, monitor for symptoms of anthracnose infection in the weeks after planting, which can present as browning and wilting of the lower leaves (photo 9-8).

Cultural practices that promote good air circulation and rapid drying of the fruit should be practiced to reduce the spread of the disease since spores are moved primarily by splashing water. Straw mulch between rows will help reduce disease spread; conversely, plastic mulches promote disease spread

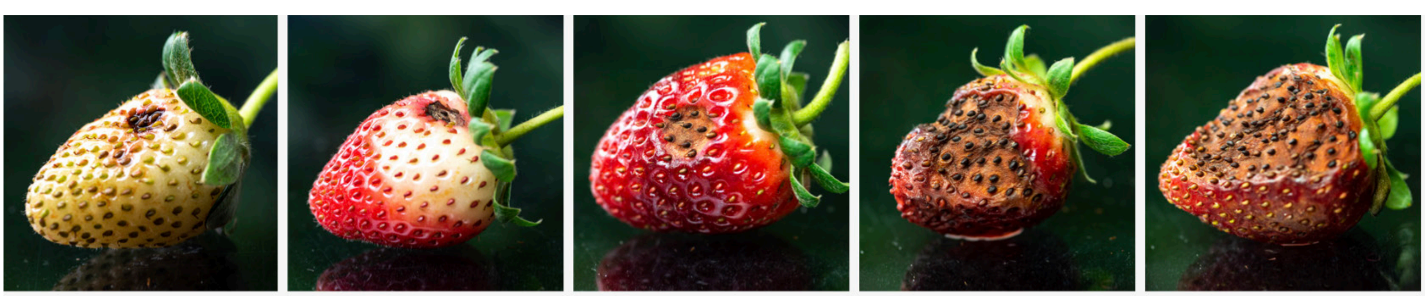


Photo 9-7. Anthracnose fruit rot (M. Dowling, www.phytographics.com).

Photo 9-8. Anthracnose symptoms in a field recently planted with plug plants (K. Orde).

Photo 9-11. Translucent leaf spots from top of leaf (J. Maas).

Photo 9-9. Green petal (E. Pate).

Photo 9-12. Calyx affected with angular leaf spot (M. Ellis).

Photo 9-10. Angular leaf spot (D. Handley).

Photo 9-13. Leaf spot (K. Orde).

since they serve as "trampolines" for raindrops. Similarly, overhead irrigation can distribute spores and lead to new infections once an epidemic has started.

Green Petal

Scientific name: 'Candidatus' *Phytoplasma asteris*

The incidence of infected plants is generally low but can be as high as 20%. This disease is usually more of a curiosity than a serious problem.

A characteristic symptom of this disease is that infected plants develop flowers with green petals that later turn red. Such flowers either fail to form fruit, or they form fruit composed mostly of large green seeds (photo 9-9). Fruit from infected plants may also have a "button berry" look. In a few varieties, small leaf-like structures replace individual seeds and grow out of parts of the berry (this is also a symptom of the aster yellows disease). The young leaves of plants infected with green petal may be extremely stunted and have yellow edges.

Green petal is caused by a microorganism similar to a bacterium in a group known as phytoplasmas. This organism also infects different clover species and persists in the gut of leafhoppers that feed on infected plants. The leafhoppers can then spread the disease to healthy plants as they continue feeding.

Strawberry varieties vary considerably in their resistance or tolerance to this disease. When infected plants are noticed, they and any daughter plants should be removed from the field to prevent additional spread.

Leaf Damage

Bacterial Angular Leaf Spot

Scientific name: *Xanthomonas fragariae*

Angular leaf spot is a bacterial disease that is particularly problematic in nursery production, especially for those who export plants to Europe due to the European and Mediterranean Plant Protection Organization (EPPO) considering *X. fragariae* as an A2 quarantine pathogen. This means any strawberry plants sent to Europe must be derived from mother plants certified free of the disease.

Early symptoms are small, water-soaked spots (lesions) on the lower leaf surface that are angular in shape because their expansion is limited by the network of fine leaf veins (photo 9-10). When infected leaves are picked and held up against bright light, these lesions are characteristically translucent (photo 9-11), although they appear dark green against a normal or dark background. As the disease progresses, numerous lesions can join together to cover large portions of the leaf. These become visible on the upper leaf surface as reddish-brown regions eventually die, giving the leaf a ragged appearance. A symptom that helps distinguish angular leaf spot from other diseases is the presence of a thick fluid that forms on the underside of infected leaves during wet weather, then turns into a brownish varnish-like film as it dries. Economic losses from the disease are most common when the bacterium infects the berry caps; this symptom is called "black cap" (photo 9-12). There are varying degrees of susceptibilities within commercial strawberry varieties. Some can tolerate foliar infections without yield being reduced, and others become stunted and have a reduced canopy, causing an increase in sunscald susceptibility.

The angular leaf spot bacterium is introduced into strawberry fields on infected planting material and is systemic within the vascular system, infecting new leaf tissue, crown tissue, and daughter plants. The bacteria can also persist in the soil in infected leaf debris. It is spread by splashing water (rain, overhead irrigation), and infection is favored when wetting events are associated with moderate daytime temperatures and low night temperatures. Bacteria that develop within leaf lesions can ooze to the surface during periods of rain, fog, and dew, and then cause new infections if they are disseminated by splashing water.

Once established, angular leaf spot is a difficult disease to control. Treatments with copper compounds and experimental antibiotic applications have been largely ineffective. Removal of infected leaf debris, to whatever degree possible, is ideal. Avoid overhead irrigation when the disease is present. Rotate out of severely infected fields for at least 1 year to eliminate inoculum sources within a field, since the bacterium has no other common host.

Leaf Spot

Scientific name: *Mycosphaerella fragariae*

Symptoms of leaf spot first appear as circular, deep purple spots. The spots enlarge, and the centers turn grayish to white on older leaves and brown on young leaves (photo 9-13). A distinct reddish-purple to rusty brown border surrounds the spots (lesions).

The leaf spot fungus overwinters in lesions on living leaves and overwintering structures are produced in dead infected foliage. Spores are produced from these spots and overwintering structures in the spring and summer and are spread by splashing rain. The infection then occurs if leaves remain wet long enough. Infection can occur at temperatures of approximately 50–80˚F, although 68–77˚F is considered ideal. Lesions can also develop on fruit (causing the descriptively named "black seed disease"), stems, petioles, runners, and caps in very wet years. Leaf spots on the caps of fruit can make berries less attractive and unmarketable.

Although many varieties have good to moderate levels of resistance to this disease, some are very susceptible. In general, protective fungicide sprays are needed only on highly susceptible varieties during very wet fruiting periods. Under such conditions, sprays may be especially beneficial if wet weather the previous autumn provided high levels of overwintering spore inoculum. A recent study in the province of Quebec, in eastern Canada, found 40% of fields had leaf spot present. Growers typically don't treat specifically for leaf spot, although some broad-spectrum fungicides and mixes aimed at fruit rots control leaf spot as well. Mowing of old leaves at renovation may provide a limited measure of cultural control.

Pestalotia Leaf Spot and Fruit Rot

Scientific name: *Neopestalotiopsis* spp.

In 2012 there were reports of isolated strawberry plants showing disease symptoms in Florida. Each year since 2017 there have been an increase in these outbreaks. The fungi recovered are taxonomically poorly understood and have gone through multiple reclassifications. The most recent research in 2020 indicated the pathogen causing these outbreaks is *Neoplestalotiopsis* spp. although due to difficulty in pronouncing this pathogen, it is referred to by its previous name, *Pestalotia* spp.

The symptoms of this disease are commonly found on the roots and crowns and contributing to plant establishment difficulties. Leaves and fruit can also be affected by the pathogen (photos 9-14 and 9-15). Fruit can have lesions 2–4 mm in diameter and are dry, light tan, slightly sunken, and irregular in shape during the early stages. Lesions grow in size and eventually are covered by shiny black droplets of liquid containing spores. Under humid conditions, dense, white mycelium may also form on the lesion. Eventually, the entire fruit is affected and mummified.

On leaves, light to dark brown spots of different sizes are irregularly distributed and in more advanced stages, black can develop in older necrotic tissue. In recent outbreaks in Florida, mass spotting often produced blight-like necrosis of broad areas of the lamella, eventually killing the leaf. The fungus produces spores on the surface of infected tissues that are dispersed by water, and disease outbreaks are favored during periods of heavy rains and warm temperatures. When conditions were highly conducive for disease development and plants were severely impacted, the disease also contributed to poor development of the plants, which became stunted and produced small leaves.

It is believed that this pathogen is transported with strawberry transplants from nurseries.

Leaf Scorch

Scientific name: *Diplocarpon earliana*

This disease's symptoms are numerous, small, irregularly shaped, purplish spots that develop on the leaves (photo 9-16). The spots differ from those of leaf spot in that they are purple throughout (no light center) and have no well-defined border. When numerous, blotches may grow together, causing the entire leaflet to appear purplish or reddish-brown. When the disease is progressed, leaves turn brown, dry out, and result in the margins curling up and resembling a burned (scorched) appearance. Besides the foliage, the cap of the fruit will die, causing less of a market grade.

Spores of the leaf scorch fungus are produced in the spring on dead leaves that became infected the previous year. They are spread by wind and splashing rain and infect during periods of leaf wetness when the weather is warm (68–86˚F is ideal). The disease is most likely to reach significant levels on older plantings of susceptible varieties since this allows inoculum to build up over time. Disease control strategies are similar to those for leaf spot.

Leaf Blight

Scientific name: *Phomopsis obscurans*

Leaf blight occurs sporadically—symptoms begin as one to several circular dark-brown centered spots surrounded by light-brown rings with purplish halos. As the disease develops, spots enlarge between prominent veins to form V-shaped lesions with the widest part of the V towards the leaf margin (photo 9-17). The entire leaflet may turn brown if multiple infections occur or if the petiole becomes girdled. Leaves are most susceptible to infection when they are less than two weeks old and become more resistant with age.

The leaf blight disease cycle is not well characterized. The fungus overwinters on infected leaves that remain attached to the plant. It produces spores in the spring that are spread short distances by splashing rain to cause new infections. Unlike leaf spot and leaf scorch, there are no varieties with good resistance to this disease. If control is needed (such as when the disease was serious the previous year and when spring weather is wet), broad-spectrum fungicides or mixes should be effective.

Powdery Mildew

Scientific name: *Sphaerotheca macularis*

Powdery mildew severity is most pronounced in regions with high humidity and moderate temperatures such as near the Great Lakes and ocean coasts. The most conspicuous symptom is the rolling of infected leaves in the late summer and fall; purplish or reddish blotches (and sometimes a powdery growth) are apparent on leaves' undersides (photos 9-18 and 9-19). Numerous pepper-like, black specks often appear in the fall on the leaf surface. Flowers and fruit may become infected and covered with a fine white fungal growth, but this occurs only rarely (photo 9-20).

Unlike many fungal diseases, rain is not necessary for disease spread. Infection periods are favored by humid weather and temperatures between 58–68˚F, resulting in severe foliage infection occurring early or late in the season.

Resistance to fungicides is widespread for this disease, so rotation of fungicides is essential. Cultural controls other than avoiding highly susceptible varieties have not been identified. The effect of late-season leaf infection on the following year's yield is unknown.

Aster Yellows

Aster yellows is caused by a microorganism similar to the one that causes green petal and is also spread by leafhopper feeding. Fruit symptoms of the two diseases are very similar and may be almost indistinguishable; however, plants infected with aster yellows do not form button berries, nor do the green flower petals turn red. The leaves of infected plants are generally cupped, smaller than normal, and chlorotic to reddish in color. The plants eventually wilt and die. The symptoms on fruits and flowers distinguish aster yellows from other causes of plant collapse (photo 9-21).

Aster yellows often kills infected strawberry plants within two months of the first appearance of symptoms, which limits its ability to spread within strawberry plantings. However, the organism has a very wide host range, so reinfection from outside the planting may occur. This is not considered a serious disease of strawberries in the East, and no specific control measures are recommended.

Phyllody

Phyllody refers to an abnormal development of either the flower, fruit, or leaves on the plant (photo 9-22). Non-infectious phyllody is believed to be connected with too many chilling hours, but is not persistent and will go away. Infectious phyllody is caused by an infection by a phytoplasma, which are bacteria that are transmitted primarily by

Photo 9-14. Pestalotia leaf spot (M. Hu).

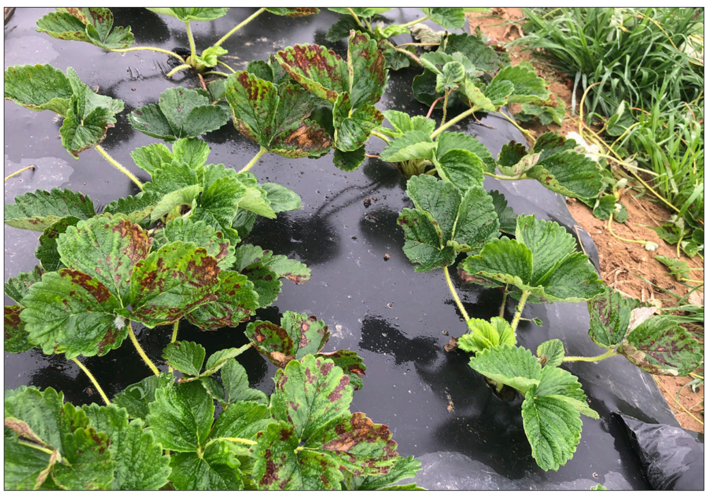


Photo 9-15. Pestalotia leaf spot (M. Hu).

Photo 9-16. Leaf scorch (K. Demchak).

Photo 9-17. Leaf blight (*Phomopsis*) (M. McGrath).

Photo 9-18. Rolling of powdery mildew infected leaves, with purple blotches (K. Orde).

Photo 9-19. Powdery mildew growth on the underside of leaves (D. Handley).

leafhoppers. Both aster yellows and green petal are diseases that cause phyllody. If infected, symptoms will not disappear. Submit samples to a plant diagnostic lab for proper identification.

Root Damage

Red Stele

Scientific name: *Phytophthora fragariae*

Red stele is a major disease of strawberries in growing areas like the Northeast and upper Midwest, where cool, wet soil conditions occur. Symptoms often appear just before harvest due to the compromised crown and the stress of setting fruit. Diseased plants are typically stunted and wilted and often have off-color leaves. Young leaves show a blue-green coloring, and older leaves having a reddish-yellow tint. They often occur in groups, usually in the wettest sections of the planting. With pronounced differences in resistance among varieties, the severity of the injury can range dramatically.

Because other factors (for example, root weevil grubs) can cause somewhat similar symptoms, red stele is best diagnosed by digging up moderately diseased (not dead) plants in May or June and examining their roots. Typically, the fine lateral roots will be missing, and some of the primary fleshy roots will be rotted from the tip back (photo 9-23). Cut one or more of these roots lengthwise just behind the rotten zone and look for the diagnostic reddish core (or "stele" in botanical terminology) (photo 9-24).

The red stele fungus is not present in all soils but can persist as dormant spores for many years once it has been introduced. In the fall and spring, some of these spores germinate to start the infection cycle. A different, infective spore type is then produced when the soil is so wet that it puddles, and these spores swim through the water-filled soil pores until they reach and enter strawberry root tips. The fungus grows up through the roots, causing them to rot. Other infectious spores are produced from diseased roots during subsequent periods of soil saturation, and they swim to healthy roots to cause new infections. This process can repeat itself many times whenever the soil is saturated, and temperatures are favorable (45–60˚F is optimum). Dormant spores produced inside the infected roots are released into the soil as the roots decay; this allows the fungus to persist during unfavorable weather or rotational cropping sequences.

Many varieties are available with resistance to red stele. These are very useful for disease control and are strongly recommended in sites with a previous disease history. However, no variety is resistant to all races of the pathogen and planting tolerant varieties does not guarantee that disease will not occur.

Cultural practices that reduce the number and duration of soil saturation events (puddling) near the plant root zone are also very important for red stele control. These practices include selecting planting sites for good surface and internal drainage, avoiding soil compaction and rutting, and using raised bed planting systems. Specific fungicides are available for red stele control and can provide significant protection, particularly when used in combination with the preceding horticultural practices. Crop rotation and fumigation are of limited value, since these techniques never eliminate all dormant spores and the fungus reproduces rapidly from those that survive.

Black Root Rot

Scientific name: Disease complex of *Rhizoctonia spp., Pythium* spp., other fungi, and *Pratylenchus penetrans*

Black root rot is a disease complex, meaning several different organisms can cause the disease. The more common causes are *Rhizoctonia* spp., *Pythium* spp. and the lesion nematode (*Pratylenchus penetrans*). Plants that are already experiencing stress from drought, frost damage, herbicide injury, or poor nutrition are most likely to succumb to black root rot. When lesion nematode is present with another organism that causes the disease, this disease progresses further than if only the pathogen or nematode were present alone. This is a major root disease problem in the Northeast due to the perennial cropping system, long history of strawberry production, and limited rotation (photo 9-25).

Photo 9-20. Powdery mildew on fruit (right) (K. Orde).

Photo 9-21. Aster yellows (A. Smart).

Photo 9-22. Phyllody in strawberry fruit (K. Orde).

Photo 9-23. Root showing red stele symptoms (D. Handley).

Photo 9-24. Diagnostic reddish core of red stele (K. Demchak).

Photo 9-25. Black root rot (K. Demchak).

Black root rot symptoms are stunting or declining plants whose roots are covered to varying degrees with black lesions. The decline in vigor is most apparent during the last couple of weeks before harvest, particularly in dry years, and may seriously affect fruit size and yield. The disease often occurs during the first fruiting year and usually becomes much more severe in the year following the first appearance of symptoms. When affected plants are dug up about when fruit begins to color, many of the fine lateral roots will be missing or dead, and irregular black patches may be visible over many of the fleshy white roots. In severely diseased plants, these black patches grow together so that no fleshy white roots are visible. The interior of blackened fleshy roots remains white, whereas the interior of affected woody roots turns black.

Management of black root rot is difficult because it has different causes that may vary from site to site. To help prevent the disease, choose planting sites with a minimal recent history of strawberry production (preferably at least a three-year rotation). Many growers in other regions fumigate land before planting to control black root rot.

Using raised bed planting systems appears to help reduce black root rot damage, minimizing soil compaction, and exercising caution with herbicide rates and applications. Some strawberry varieties appear tolerant of individual causes of black root rot, but no variety shows resistance or tolerance to all causes.

Verticillium Wilt

Scientific name: *Verticillium dahliae*

Verticillium wilt occurs sporadically. It is always a threat when new plantings are established immediately after certain crops or weeds have been growing in the same soil. Crops that can build up dangerous levels of the *Verticillium* spp. fungus in the soil include tomatoes, potatoes, eggplant, and pepper. Lambsquarters, pigweed, and horsenettle are common weeds that also host the fungus. Infected plants often appear to be scattered throughout the field, but their distribution is usually related to that of the infected crop or weed plants during the year(s) before strawberries were set.

Symptoms of Verticillium wilt usually appear during the first year of planting. The outer leaves of infected plants turn brown around the edges and between the veins during warm summer weather. As the disease progresses, these leaves wilt, turn entirely brown and die, while the inner leaves remain unwilted and green for some time (photo 9-26).

Photo 9-26. Verticillium wilt (B. Sideman).

Eventually, the entire plant dies. The roots of infected plants look dead but have no distinctive symptoms. The best clues for field diagnosing the disease are the presence of green inner leaves on wilting plants after the outer leaves have died and the crop and weed history of the area.

The *Verticillium* spp. fungus lives in the vascular tissue of infected plants and blocks water flow, so the plants wilt and die. Dormant resting structures of the fungus are produced within infected plants and are released and spread by wind and water to healthy susceptible plant tissue. These structures germinate in the spring when they contact new plant roots to cause the new season's round of infection. Plant-to-plant spread during the season is not considered a major factor in the spread of the disease. Verticillium wilt populations increase progressively over the years wherever host plants are available. This localized buildup of the pathogen accounts for the random distribution of infected strawberry plants in an infested field. Nursery stock plants may also be infected before planting.

Disease severity is directly dependent on the *Verticillium* spp. population that is present at the time of planting. Thus, control can be obtained by planting into soils where highly susceptible crops and weeds have not been growing for the last 3 years. Pre-plant fumigation also provides very effective control.

Nematodes

Scientific name: *Pratylenchus penetrans,* others

Several species of nematodes (microscopic roundworms) can damage strawberry roots. These nematodes feed, and some travel throughout the roots, weakening plants. Some nematodes can vector viruses, causing additional problems for the plant. All nematodes tend to be more common in lighter soils. The most common and important nematode on strawberries is the lesion nematode, *Pratylenchus penetrans* (photo 9-27). Although this nematode is an issue on strawberries, it can infect nearly 400 other plants, making it difficult to rotate to a non-susceptible host for management. In addition to direct feeding damage, this nematode can also increase the severity of black root rot when it is present in combination with certain fungi.

Nematodes travel only a matter of inches; thus, they must be present in the soil at certain levels before planting to cause significant damage. Some laboratories can determine the presence and population levels of nematodes in particular sites from soil samples collected before planting. The results from these tests can be used to guide control decisions. The labs normally supply procedures for sampling and interpretation of the obtained results.

Treatments for nematodes must be made before planting. These include fumigation, rotation, and the use of particular cover crops. Some cover crops, such as specific types of mustards, marigolds, sudangrass, and varieties of canola/mustards, appear to suppress nematodes nearly as well as fumigation.

Winter Injury

Symptoms of winter injury appear in the spring when plants resume growing. Plants damaged over the winter either do not grow or grow poorly. Damage often occurs in fields or areas where plants were not covered with mulch or snow during the coldest part of the winter, When cut in half, crowns with winter damage are brown or reddish-brown. Part or all of the crown may be damaged, including the flower trusses (photo 5-1). An undamaged crown should be creamy white throughout. Some diseases that occur infrequently can cause browning or reddening of the crowns, but winter damage is a much more common cause of this symptom.

Photo 9-27. Root lesion nematode (J. Potter).

Winter injury occurs in various forms. Cold, dry winds can draw moisture from the crowns and injure tissue. Rapid freezing in autumn can cause ice to form within the crown and injure the vascular system. Freezing and thawing cycles in the spring can sever roots. Strawberry plants that are stressed but not killed maybe more susceptible to infection by the microorganisms that cause black root rot.

Adequate and timely straw mulching or rowcover application is the best protection against winter injury (Chapter 5). Plants on raised beds are more susceptible to winter injury, but a raised bed's benefits often outweigh this increased risk.

Further Reading

Berry Diagnostic Tool: Strawberries. Cornell University.

Converse, R. H. Virus Diseases of Small Fruits. United States Department of Agriculture–Agricultural Research Service Handbook 631.

Cooley, D. R. and S. G. Schloemann. Integrated Pest Management for Strawberries in the Northeastern United States. University of Massachusetts Cooperative Extension Bulletin C211.

Funt, R. C., M. A. Ellis, and C. Welty. Midwest Small Fruit Pest Management Handbook. Columbus, Ohio: Ohio State University Press, 1997.

Maas, J. L. Compendium of Strawberry Diseases, 2nd edition. St. Paul,Minnesota: American Phytopathological Society, 1998.

New England Small Fruit Management Guide. Cooperative Extension Systems of Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.

CHAPTER 10

Weed Management

Successful weed management is among the greatest challenges of commercial strawberry production. Indeed, the most common reason for plowing down a strawberry bed is weed infestation. Nearly all aspects of strawberry production can have an impact on weed populations, and growers must constantly consider how their cultural practices may impact weed growth in their fields. Weeds compete directly with crop plants for nutrients, water and light, harbor insect and disease pests, and interfere with pesticide sprays, nutrient applications and harvest. Controlling them is essential for maximizing yield and fruit quality, and demands a significant amount of time and resources from every grower.

Integrated Weed Control

An integrated strategy is the most successful long-term approach to managing weeds, including crop rotation, cultivation, mulching, and herbicides. By exploiting a variety of methods most weeds can be effectively managed. Over-dependence on one technique, e.g., chemical herbicides, can lead to disastrous weed problems if the weeds develop resistance, the application goes wrong, or environmental conditions prevent the chemical from working effectively. For the best long-term results, growers should exploit all the tools available to them to manage weeds, including good pre-plant practices, crop rotation, cultivation, and mulching.

Reducing Weeds Prior to Planting

Good weed management starts with the site you choose. It is always best to choose a site where the weed pressure, especially from perennial weeds, is low. For example, select sites that have previously had well managed cover crops and/or cash crops that either smothered weeds or allowed effective cultivation and chemical controls (see Chapter 2). Strawberries grown in a matted row system are usually carried over for 2–5 harvest seasons. During that time, weeds are managed with a variety of methods, but certain species tend to build up over time, due to some ability to escape the control strategies employed. When the bed is plowed down, the site should be managed to address those weed problems before it is replanted to strawberries. This may take several seasons to successfully accomplish. A minimum 3-year gap is recommended between plantings of strawberries in the same site. This time should be used to eliminate problem weed species, and to reduce soil borne disease and insect problems.

Crop Rotation

Crop rotation should be a primary means of reducing problem weeds prior to planting. Cover crops can be grown on a site prior to strawberries to smother emerging weeds, provided they do not produce seeds themselves (see Chapter 2). Crops grown prior to strawberries may also to allow the use of herbicides labeled for problem weed species in the field (but not necessarily for strawberries). In these situations, however, be aware of the possibility of herbicide carryover. Crop rotations can provide additional benefits, such as increasing soil organic matter content. Sweet corn, in particular, is a good rotational crop with berries, especially if the stover is worked into the soil to retain organic matter. Early sweet corn can be followed with oats to provide significant weed suppression in a single year. Sudan grass and marigold cover crops have a suppressive effect on nematodes, can reduce soil disease inoculum when included in the rotation. Cover crops that are unrelated to berries (such as grasses and grains) usually make the best rotational companions (see Chapter 2).

Crop Rotations Best For Organic Strawberry Plantings

Although strawberry growers who employ chemical herbicides can typically get 3 or more harvest seasons from a single planting, aiming for a single harvest season for a planting is probably the most realistic option for most organic growers to successfully manage weeds. For example, plant dormant crowns in year 1, harvest a crop in year 2, then immediately plow the bed down and plant rotation crops for 2 or more years. This greatly reduces the buildup of problem weed species. However, some new strategies including delayed planting, strip tillage, and other reduced tillage practices may allow organic growers to extend the productive life of their strawberry beds and thus improve their profitability.

Soil Fumigation

Fumigation can greatly reduce weed seed banks in the soil prior to planting. In addition to weed control, fumigation also offers control of soil borne insects and diseases. However, soil fumigant chemicals are under increased scrutiny and regulation due to negative environmental impacts and effects on the soil ecosystem. There is only a short application window (spring and fall) available, and the fumigants are usually professionally applied, making the process very expensive. Although it is no longer a common practice in the Northeast, fumigation may be considered among other options, especially for particularly difficult weed problems, when alternatives have not been effective.

Managing Weeds During the Planting Year

Delayed Planting

Timing of planting can significantly impact weed pressure in strawberry fields. Although early season planting is typically recommended to provide the longest possible growing season, delaying the planting date can be used to manage weeds in a new strawberry bed. By preparing the ground in the fall or in the early spring, then allowing the first flush of spring weeds to germinate before planting, early spring weeds can be killed before planting with a light cultivation, contact herbicides, or flaming. Eliminating the first flush of weeds and planting into a warmer, drier soil, reduces the need for early cultivation and hand weeding. However, delaying planting by 4–6 weeks can have a negative impact on the quality of stored strawberry plants, so it is important to discuss timing of planting with the nursery well in advance to assure that the plants will be stored and shipped appropriately.

Strip Tillage

Another strategy for managing weeds in the planting year is to use strip or zone tillage. In the late summer of the year prior to planting a cover crop of oats or winter rye is grown on the site. Oats will winter kill, but rye will need to be crimped, mowed, or killed with an herbicide the following spring. The dead plant residue is left undisturbed on the soil surface except for narrow (8–12 inches) strips or zones that are tilled for the strawberry plants. Leaving most of the soil surface untilled with a heavy plant residue will prevent most weed seeds from germinating. Rye residue lasts longer than that of oats, but killing winter rye can be problematic. Zone tillage requires specialized equipment to make the soil strips suitable for good plant growth. The equipment is both expensive and heavy, requiring a fair amount of horsepower, but it can be used for many crops on the farm. Strawberry plants are usually spaced close together in this system, from 6–12 inches apart within rows, to provide better and faster plant cover to inhibit weed growth in the cultivated strips (see Chapter 4). Toward the end of the season, as the residue breaks down, weeds can once again become an issue, and hand weeding will be required within the tilled strips of the plant rows.

Weeds In Established Plantings

Cover Crops Between Rows

Cover crops such as oats, sorghum/sudan or buckwheat may be seeded in the aisles between the plant rows to prevent weed growth (photo 10-1). The grasses should be mowed when they reach a height of 2 feet to prevent them from shading out the strawberries, and enough nitrogen fertilizer and water must be applied to prevent competition between the cover crop and the strawberries.

Photo 10-1. Interplanted sudan grass in a matted row planting (M. Pritts).

Cover crops will suppress weeds in the aisles and the grass residues will help provide winter protection, but hand weeding within the plant rows will still be needed. Grower results with this technique have been mixed, and it requires more management time and effort, but some studies have found it to be effective.

Photo 10-2. Basket weeder (D. Handley).

Cultivation

Weeds can be managed with a variety of cultivation tools, such as tine cultivators, basket cultivators (photo 10-2), blind cultivators (e.g., Lely), and/or finger weeders (e.g., Buddingh or Reigi; photos 10-3, 10-4). Tine weeders are designed to work best when weeds have germinated but have not yet actually emerged through the soil surface. Shallow cultivation is generally preferred over deep cultivation because continuous deep cultivation promotes further weed seed germination and degrades soil quality. Tine weeders, finger weeders, basket weeders and others can be used very effectively early in the season or shortly after renovation, when weeds are very small (photo 10-5), as long as they are combined with vigilant hand weeding within the plant rows where the cultivators can't reach. When used judiciously every 10–14 days, these cultivators can eliminate most weeds in a new planting while keeping soil disturbance to a minimum. Cultivating becomes more challenging during the summer when runner plants are in the aisles and in the path of the cultivators. Using sweep blades to push the runners out of the way in front of the cultivating tines can work, but generally the need for hand weeding will become more intense as the season progresses. Cultivation is often limited by weather and the location of the weeds in the beds. However, it has a low environmental impact, can improve soil aeration, and is a relatively simple procedure.

Photo 10-3. Finger weeder (D. Handley).

Flaming weed seedlings between the rows has also been used with some success in strawberries, but the equipment and fuel are costly, and the burners must be well shielded to prevent burning the strawberry plants. The operator must use extreme caution to avoid injuring strawberry plants, and to prevent setting fire to mulch and brush surrounding the planting. This technique has the advantage of not disturbing the soil surface, which brings more weed seeds up from the soil.

Photo 10-4. Reigi finger weeder (D. Handley).

Mulching

Mulch is not typically used on matted row beds in the planting year for weed control, because it interferes with runner plants rooting. Straw mulch is applied late in the fall to cover the plants for winter protection (see Chapter 5) and is raked into the aisles the following spring to provide some weed control by covering the soil between the rows. However, the importance of using straw free of weed seeds cannot be overemphasized. Many weeds are introduced into strawberry fields through contaminated straw. Growers should consider growing their own straw, or they should work with the grain grower supplying the mulch to ensure that proper measures are taken to keep the grain field weed-free. Ideally, straw should be cut before it sets seed to prevent volunteer grain from germinating in the strawberry field.

Plastic mulches can also be used to reduce weed problems in strawberries, although organic regulations may restrict the length of time that plastic mulch can stay in place, generally to 1grow-ing season. Planting strawberries through black plastic will eliminate much of the weed pressure within the planting, but it prevents the use of runner plants to fill out the row. Therefore, plasticulture systems require about 2–3 times as many plants as a matted row system at planting, and runners should be removed (see Chapter 4).

Specialized equipment for making beds and laying plastic mulch is required, but vegetable growers would likely have such equipment on hand. Research is underway to evaluate the feasibility of removing the plastic in the second season without disturbing the plants, or using degradable mulch, and allowing the planting to become a matted row for harvest a second year. It is hoped that weed problems would be reduced from having the soil covered for the previous year.

Photo 10-5. Weeds at the very young "white thread" stage (D. Handley).

Herbicides

NOTE: Herbicide names used in the following discussion are to serve as examples only. They are not necessarily registered for use in your state or province. Pesticide labels change often, and companies may decide to discontinue a product. Read product labels prior to use.

Herbicides are used by most growers because they are often effective and economical. However, relatively few herbicides are currently registered for use on strawberries in the United States and Canada (see local pest management recommendations for registered products), and these are not effective against all weeds. Therefore, herbicides cannot be relied upon exclusively for weed control; crop rotations, mulching, hand weeding, and cultivation will all be necessary components of an effective weed management program.

When using herbicides in combination with crop rotation and cultivation, be aware of potential carry-over effects of herbicides on subsequent crops. Within a strawberry field, cultivation can dilute any herbicide that was applied previously and can bring new weed seeds to the soil surface where they can germinate. Cultivation should be performed before applying an herbicide, unless the herbicide is meant to be preplant incorporated.

Herbicides need to be applied correctly to maximize performance. Herbicide performance can be optimized by:

- Using the right herbicide for the problem weed, soil type, and time of year
- Using the appropriate rate
- Timing the application properly
- Proper placement of the herbicide
- Providing conditions most appropriate for herbicide activation

Preëmergent herbicides interfere with seedling establishment, so conditions must be favorable for weed growth (warm, moist soils) for these chemicals to work. Herbicides must be moved into the top few inches of soil where the weed seeds reside, usually through rainfall or irrigation. Herbicides that remain on the soil surface or are washed or tilled below the weed seeds will not be effective. In most soils, about 1 inch of water is required to move an herbicide into the soil, but sandy soils may require less. Additionally, readily soluble herbicides, such as terbacil, may require less water to reach the weed seed zone, especially in sandy soils (see table 10-1). Preëmergent herbicides should be applied just prior to the germination period of weed seeds. For most species, this occurs in the spring. Napropamide (Devrinol) or DCPA (Dacthal) can be applied in the spring, but may also be applied in the fall, and will move into the seed germination zone during the winter to inhibit seedling establishment in the spring. However, terbacil (Sinbar) applied in the fall may wash out of the seed germination zone during winter since it is very soluble. Furthermore, it can burn new growth (photo 10-6) if applied in early spring, unless it is washed off the leaves immediately after application. Therefore, terbacil is most commonly applied after harvest, during the renovation process.

Photo 10-6. Injury from terbacil (Sinbar) (M. Pritts photo).

Postemergent herbicides will kill established plants, unlike preëmergent types which typically are only effective on germinating seeds. Most post emergent products are not very specific and will kill a wide range of species, including crop plants, if not used properly. Phenoxy herbicides (Group 4) such as 2,4-D amine and 2,4-D choline salt products (Formula 40, Embed), will kill most established broadleaf weed species, such as dandelions, shepherd's purse, curly dock, but will also injure strawberry plants unless applied when the plants are not actively growing. This limits application of these products to specific windows of opportunity during the year. For strawberries in a matted row, postemergent herbicides are used in the summer as part of the bed renovation process just after harvest, and prior to mulching in autumn, when the strawberry plants are dormant but some broadleaf weeds are still growing. Clopyralid (Spur, Stinger) is in the same herbicide group, but may be applied any time after harvest and offers better control of broadleaf weeds growing later in the season including clover, vetch and thistle. ACCase inhibitors (Group 1) such as clethodim and sethoxydim (Select, Poast) can provide postemergent control of many grass species, which are not controlled by 2,4-D products, and will not injure broadleaf plants, including strawberries, if applied under appropriate conditions. Although the window of opportunity for using these products is larger than that for 2,4-D, they work best when the grass weeds are small (6–10 inches tall) and actively growing, i.e., not dormant or under stress. An addition of a crop oil to the spray is usually recommended to improve its effectiveness.

Other postemergent products have little to no specificity and will kill nearly all plants that they contact. They include systemic products such as glyphosate (Roundup) and burn-down chemicals such as paraquat (Gramoxone).

Table 10-1. Selectivity of preëmergent strawberry herbicides labeled in the United States

Herbicide	**Degradation/Half life**	**Weeds controlled**
Napropamide (Devrinol) Group 15	60 days (less in sunlight) 24-hour incorporation	Annual grasses, chickweed, knotweed, groundsel, lambsquarters, pigweed, purslane, pineapple weed annual bluegrass, large crabgrass, barnyardgrass
DCPA (Dacthal) Group 3	30 days 72-hour incorporation	Chickweed, crabgrass, foxtail, lambsquarters, field pansy, purslane bluegrass, barnyardgrass, johnsongrass, knotweed,nightshade, panicum, pigweed, spurge <u>No activity:</u> galinsoga, mustards, nutsedge, ragweed, smartweed, velvetleaf
Terbacil (Sinbar) Group 5	90 days 2-week incorporation	Chickweed, lambsquarters, mustards, crabgrass, foxtail, prickly lettuce, shepherdspurse <u>Little activity:</u> dandelion, milkweed, thistles, vetches, cinquefoil, sedges, quackgrass, red sorrel, groundsel, nutsedge NOTE: Sinbar can cause crop injury if used on sensi-tive varieties or on soils low in organic matter.

Such herbicides should only be used to kill weeds on a site prior to planting strawberries or, in the case of paraquat, between strawberry plant rows with a with a specially shielded sprayer to control weeds in the aisleways without contacting strawberry plants in the rows. Certain preëmergent products may also be registered for use with shielded sprayers between plant rows, but unlike the products mentioned above, are not safe for use over strawberry plants because they will cause severe injury.

Herbicide Programs For Matted Row Strawberries

Pre-plant: If the intended planting site has established perennial weeds, an application of a broad-spectrum systemic herbicide such as glyphosate may be applied in the fall before planting to provide control. Certain preëmergent herbicides are registered for use prior to planting for control of annual and some perennial weeds, including oxyfluorfen (Goal) and pendimethalin (Prowl). These require a waiting period of 1–30 days after application before planting, and should not be used during the growing season, unless the label allows, to avoid injuring strawberry plants.

Planting year: Following planting, several preëmergent herbicide options are available, including terbacil, which should be washed off the strawberry plants with rain or irrigation if any new leaves are present, and DCPA. Napropamide may be applied after the new strawberry plants are well rooted. Grasses emerging during the season may be controlled with postemergent applications of clethodim or sethoxydim when the grasses are small. Regular cultivation with tine or finger weeders will also help keep weeds from becoming established. Later in the summer another preëmergent herbicide application, such as DCPA or napropamide can control late germinating weeds and winter annuals. After the strawberry plants have gone dormant but before applying mulch, growers have the option of applying 2,4-D to control emerged broadleaf annuals and perennials and/or napropamide or terbacil for preëmergent control of weeds both in the fall and the next spring.

Fruiting years: In the early spring, napropamide or terbacil may be applied to control spring weed germination, if they were not applied the previous fall. Straw mulch applied in the fall over the plants should be pulled into the aisles to inhibit weed germination. After harvest is complete, 2,4-D can be applied over the beds if broadleaf weeds have become a problem. After a 3–5 day waiting period, the strawberry beds should be mowed and narrowed. Tilling equipment used to narrow the rows should be set up to also maximize impact on weeds. Terbacil can be applied to provide preëmergent and some postemergent control of summer weeds. In the weeks following renovation, napropamide, DCPA can be applied for further preëmergent control of winter annuals; clopyralid can be used to provide postemergent control of clover, vetch and thistle, and clethodim or sethoxydim may be applied to provide postemergent control of grasses. Regular, light cultivation should also be employed where possible to keep weeds from becoming established between plant rows. Herbicides applied after dormancy in the fall should follow the same recommendations for planting year beds above.

Herbicide Programs For Plasticulture

The same herbicide products, rates and timing used for the perennial matted row system should not be used for plasticulture strawberry production. Herbicides sprayed on plastic mulch will be washed by rain or irrigation down the sides of the plastic and into the planting holes. This results in a concentration of herbicide around the plants that may injure or kill them. Black plastic mulch provides excellent weed control around the plants, but weeds will still emerge and become problematic between the rows of plastic and, most importantly, within the planting holes. Clear plastic mulch offers no effective weed control, and mulch colors other than black may offer only limited control.

As with the matted row system, broad spectrum systemic or contact herbicides including glyphosate and gramoxone can be used in the summer or fall before planting to kill both perennial and annual emerged weeds, but these offer no control of weed seeds in the soil. Napropamide may be applied to the beds as a preëmergent herbicide prior to the application of the plastic mulch, to provide some control of germinating weeds in the aisles and planting holes. Following planting, herbicide applications are limited to shielded applications

Table 10-2. Specific problem weeds in strawberry plantings.

Weed	Control
Bindweed	Root system can grow as deep as 20 feet in the soil. Regular cultivation and systemic herbicide treatments may be needed for 2 years to get good control.
Butter-and-Eggs	Reproduces by both seeds and rhizomes. Plants produce large numbers of seeds from June through October. Spot sprays with a systemic herbicide, and fallowing between plantings are recommended.
Canada plowing thistle	Extremely vigerous rhizomes. Deep plowing every 2 weeks for 2 years is required for control without chemicals. Otherwise, treat with clopyralid in summer or spot spray with a systemic herbicide in autumn, then cultivate after 2 weeks.
Chickweed	Control is difficult because seed germination occurs over a very long period of time, both in autumn and in early spring. An early September application of a preëmergent herbicide is needed for control. Postemergent applications of 2,4-D in the fall can kill established plants.
Clovers	Reproduces by seeds and rhizomes. Not susceptible to preëmergent strawberry herbicides, postemergent treatment with clopyralid after harvest can be effective. Rotate into a crop where clovers can be controlled before replanting to berries.
Horsetail	Resistant to almost all herbicides because it is not a grass or broadleaf weed. Drainage and regular cultivation will aid in control.
Nutsedge	More closely related to a broadleaf weed than grass; most available herbicides have little effect. Nutlets form in the soil in midsummer while strawberries are fruiting; so once established, populations are difficult to suppress. Postemergent 2,4-D applications at renovation and/or in the fall can help suppress nutsedge. Rotation, fallowing and fumigation, coupled with good soil drainage, will aid in control. Plowing but not tilling in late fall will expose some nutlets/tubers to cold temperatures and kill them.
Oxalis	Seeds germinate over a long period of time and plants can overwinter, making control difficult. Preëmergent herbicides applied at periods throughout the growing season can help. Cultivate and hand pull prior to seed formation. Postemergent 2,4-D applications at renovation and/or in the fall can control established plants.
Purslane	Cut plants can re-root after cultivation; seeds can mature on uprooted plants. Do not allow plants to grow larger than 3 inches prior to cultivation, and ensure that herbicides are applied prior to seed germination.
Quackgrass	Reproduces by extensive rhizomes and seeds that germinate over a long period of time. Somewhat resistant to postemergent graminicides. A combination of cultivation and a nonselective systemic herbicide should be used to eliminate this weed prior to planting.

between the rows to control weeds in the aisleways. Cultivation may also provide good weed control between the beds, but care must be taken to avoid tearing the plastic with the equipment. Weeds emerging from the planting holes must be controlled by hand, emphasizing the importance of good preplant weed management to reduce the number of weeds that emerge after planting.

Regardless of attempts to optimize performance, herbicides alone will not be sufficient to fully manage weeds. In strawberry beds, not all weed species that emerge will be controlled by the herbicide products presently available (table 10-2). Growers should carefully monitor weed species, growth stages and populations in their fields and determine the best management approach for each situation.

Geese for Weeding

Geese are used occasionally for weed control in new strawberry fields because they preferentially eat young grasses. They are especially useful in wet years when grasses are abundant, herbicides do not work, and the fields are too wet to cultivate. An entire acre may be kept free of grasses by 6–8 geese. However, the geese must be confined to the strawberry field with a fence, and they require supplemental food and water and a shelter. By placing the supplemental grain, the shelter, and the water at different corners of the field, the geese will be compelled to move throughout the field rather than stay in one place. Geese can be messy and may repel some pick-your-own customers.

Geese work best in a newly planted strawberry field. They should be introduced when the weeds are just starting to germinate—they will not readily eat established grasses. One-month-old birds are best as they have large appetites. To prevent microbiological contamination of fruits and vegetables, geese should be restricted to nonfruiting fields.

Summary

Weeds are usually the most common and significant pest problem strawberry growers face. Effective management of weeds must begin well in advance of planting. Well-designed crop rotations to eliminate perennial weeds from the field in the years before planting will greatly reduce weed problems that occur after planting. Prevent weeds from coming into the site by eliminating weed species surrounding the planting with regular mowing or tilling. Be sure to use only straw free from weed seeds when mulching, and if using compost or manure to improve soil fertility, make sure that these also are free from weed seeds. Cultivation with the appropriate tools and timing to target weeds when they are very small can be an effective strategy for managing weeds, especially in the planting year. Finally, both preëmergent and postemergent herbicides offer control of many of the weed species growers must contend with, if used according to product label specifications and regional recommendation for rates, timing, and application methods.

Further Reading

Uva, R. H., J. C. Neal, and J. M. DiTomaso. Weeds of the Northeast. Ithaca, New York: Cornell University Press, 1997.

CHAPTER 11

Spray Application Technology

Introduction

Applying crop protectants, nutrients, and plant growth regulators can be an important part of strawberry production. During the last several years, there have been many changes in spray technology. New materials, management techniques, and application equipment have been developed. In this chapter, we present: 1) basic information for those considering purchasing spraying equipment; and 2) important considerations for maintaining and operating spraying equipment effectively.

The basic purpose of a sprayer is to deliver a product at a desired rate to targets such as crops, weeds, or soil. The sprayer must have a tank to carry the **spray mix** (the chemical plus the water in which it is carried), and the sprayer must maintain a uniform spray mix using an agitator and control the flow of liquid with a pump and valves. The liquid is atomized into droplets by nozzles or a high-speed airstream. An airstream, either part of or separate from the atomization process, may aid in delivering droplets to the target.

Coverage is the degree of spray treatment applied to all desired target surfaces (figure 11-1). When spraying strawberries, target surfaces may include soil, leaves, and/or fruit. Many products require complete coverage, which is difficult because strawberry plants and rows may be of different sizes, densities, and shapes, and not all plant parts are equidistant from the sprayer nozzles. Often, a grower must overspray parts of the target to get adequate coverage (and control).

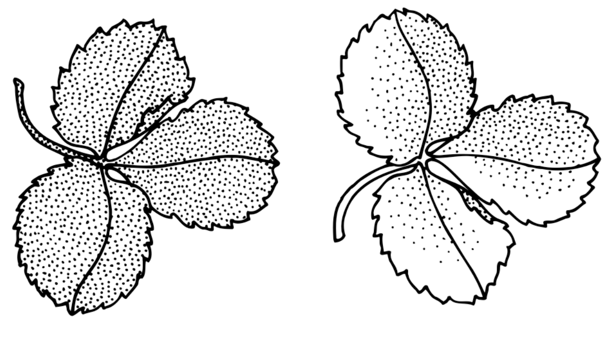


Figure 11-1. Even and uneven spray coverage on a strawberry leaf.

The application rate required for good coverage will depend on the material being applied and its purpose. Herbicide applications may require as little as 20 gallons of spray solution per acre while some fungicide, insecticide, or miticide applications may require as much as 100–200 gallons of spray solution per acre to provide the desired control. For both fiscal and environmental reasons, growers must select and set up their spray equipment properly to avoid underapplication or overapplication of products and to minimize spray drift.

Drift is the portion of the spray that misses the target or moves away from the target (plant, soil, or pest) afterward. Drift may be in the form of liquid droplets, vapor, or both. Droplet drift is related to droplet size. Large, heavy spray droplets that do not come in contact with plants will fall quickly to the ground, while smaller, lighter droplets will stay suspended longer in the air. These small droplets will be carried farther if any wind is present, resulting in drift. Vapor drift from evaporating (volatile) chemicals (for example, 2,4-D) can continue after spraying is complete. Small amounts of highly volatile pesticides can collect and remain undiluted when air is stable; this vapor can ultimately injure susceptible plants well outside the treated area.

To reduce the potential of spray drift, use larger nozzles with higher flow rates, at a lower pressure - but be aware that minimizing spray drift will compromise spray coverage. If this does not provide adequate coverage, use a higher spray volume. Keep pressure high enough to maintain the spray angle and spray distribution. Nozzle manufacturers offer several new nozzles that are designed to reduce spray drift without changing sprayer settings. Drift can also be minimized by using low-volatility chemicals that reduce vapor drift. Other ways to reduce drift include:

- Consider using antidrift additives, which increase the surface tension of the spray at the nozzle orifice to produce fewer fine droplets.
- Spray when wind speed is less than 5pmh.
- Spray when relative humidity is high, to reduce evaporation that decreases the size of droplets after leaving the sprayer.
- Use chemicals that require large droplets.

Choosing Power Spraying Equipment

Before purchasing a sprayer, consider existing and future farm plans. Consider the area and crops to be sprayed. Different crops have different spraying requirements, such as application rates and the timing of applications. A field's layout dictates the available space for maneuvering equipment. A small area may only need a backpack sprayer, but as size increases, a small sprayer pulled by an ATV or a tractor-mounted or trailered boom sprayer may be more appropriate. If future plans include expansion, purchasing a sprayer today with excess capacity may be to your advantage in the future.

Strawberry sprayers used today are usually powered, broadcast, boom-type sprayers. These may or may not include some form of air-assisted atomization and/or spray delivery. Very small commercial growers, homeowners, and hobbyists may choose smaller, handheld manual sprayers. This discussion will not include air-blast or orchard-type sprayers, which are generally not recommended for making broadcast applications to low-lying row crops such as strawberries because they can cause more drift, and therefore off-target effects, than boom sprayers.

Sprayers are either tractor-mounted or trailer units. Tractor-mounted units are carried on the three-point hitch and are relatively compact and easy to maneuver. However, this arrangement transfers more weight from the front to the rear tractor tires, and ballast weights may be needed on the front end of the tractor to maintain stability and steering control, especially on hilly terrain. Mounted sprayers are powered from the tractor through the power take-off (PTO) shaft.

Trailer sprayers are heavier than tractor-mounted units. They have larger tanks and wider boom arms. Trailer sprayers are most often powered by the tractor PTO, but some may have a separate engine to power the pump and/or air system. Both tractor-mounted and trailer units may use air systems for atomization and/or spray delivery.

Most strawberry treatments are made using nozzles and booms configured for a broadcast or uniform application across the entire boom width. This is an appropriate application technique for materials that are applied across the entire field. However, not all applications need to target the soil as well as the strawberry plants. Directed spraying techniques place the application where it is needed. Banding types of nozzles, such as the even flat fan nozzle, provide a uniform application of spray solution across most of the spray pattern. Banding nozzles are appropriate for applications of pesticides in a narrow strip between rows (for example, the herbicide paraquat) or over rows (for example, fungicides or foliar fertilizers). Hose drops or directed spray application kits can be used to direct multiple nozzles at the sides and top of strawberry plants.

Matching the Sprayer to the Tractor

Is your current tractor capable of pulling a new, larger sprayer over variable terrain? Check the sprayer manufacturer's specifications for the tractor size (or horsepower) needed for that sprayer. The tractor must have enough power to operate the sprayer at the desired speed, even on the steepest slopes, with a full tank of spray mix. If the sprayer is powered through the tractor PTO, enough power must be available to operate the fan and pump at the rated speed, and also able to transport the sprayer at the desired speed. Make sure the tractor is heavy enough and properly ballasted to safely handle the sprayer's weight on the steepest terrain to be sprayed, especially if the sprayer is a tractor-mounted unit.

The tractor should have a gear to provide the desired speed. Some tractors have only a few gears, so the step between gears is relatively large. Remember that with PTO-powered sprayers, the fuel throttle cannot be used to regulate ground speed, since the engine must be operated to provide 540 rpm at the PTO shaft. In this case, one gear may be too fast and the next one too slow, unless the tractor has a hydrostatic transmission that provides stepless speed control.

Sprayer Tanks

Tank size may range from just a few gallons in a backpack sprayer to 500 gallons. Tanks must be corrosion resistant and easy to clean. Tanks are typically made of fiberglass, plastic, stainless steel, or steel with a durable protective coating.

A tank should have a large hatch opening for easy inspecting and filling. The hatch should have a cover to prevent spray mix from splashing out of the tank. However, the hatch must let air into the tank as the liquid is removed to prevent the tank from collapsing. A tank drain makes washing, rinsing, and draining much easier.

The use of tank rinsing aids (small spinning discs or nozzle heads) fitted in the top of the tank are recommended. They reduce the amount of washing water (**rinsate**) and time required to wash out sprayer tanks and reduce the potential for operator contamination.

Many modern sprayers are fitted with a self-fill hose for water and an induction bowl for filling to reduce the risk of operator contamination and environmental pollution caused by chemical spills. An induction bowl is a bowl with a water flushing system, usually at knee-height, eliminating the need to climb onto the sprayer or lift containers overhead. Induction bowls also usually contain an integral rinsing system to clean empty containers. There is also a trend towards closed transfer devices, a control that connects the pesticide container directly to a lid on the sprayer or induction bowl, again reducing the risk of contamination for the operator.

Sprayer Agitators

Agitation is very important to keep the spray mix uniform and to keep wettable powders in uniform suspension. The sprayer tank should have an agitator—either a jet or mechanical type. A **jet agitator** uses part of the pump output to produce a jet stream in the bottom of the tank that provides a mixing action. Jet agitators are used on sprayers with centrifugal pumps, as their high flow rates support the jet. **Mechanical agitators** are used with piston or diaphragm pumps. Mechanical agitators are simply paddle wheels or propellers in the tank.

Sprayer Pumps

Piston, diaphragm, and centrifugal pumps are all used on sprayers (figure 11-2). **Piston** and **diaphragm pumps** are positive displacement pumps; therefore, they are self-priming and can produce high pressures. Their flow rate is directly proportional to operating speed. **Centrifugal pumps** are non-positive displacement pumps; while inexpensive, they are not self-priming and have a maximum working pressure of 200 lbs/in^2 (psi).

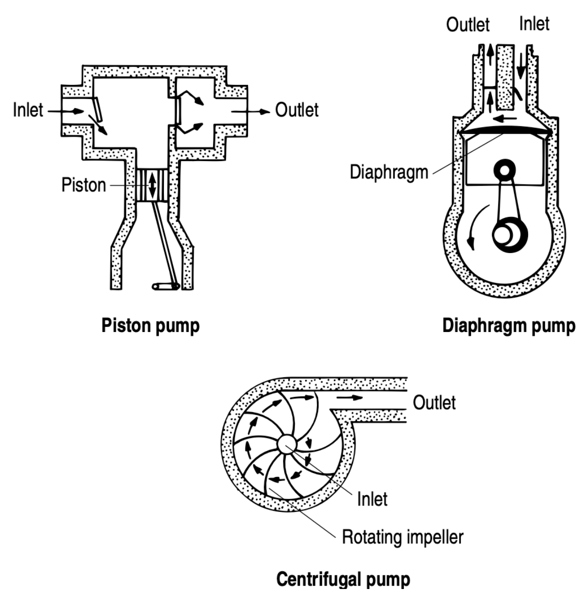


Figure 11-2. Pumps used on strawberry sprayers.

Pumps should provide the required flow rate for the sprayer nozzles and the jet agitator (if there is one), plus 20–25% extra capacity at the desired operating pressure. The extra capacity provides a reserve to compensate for wear and other factors that may reduce flow over time. Power requirements of the pump are relatively low but still need to be considered (table 11-1).

Sprayer Nozzles

Nozzle Types

Nozzles are a critically important part of any sprayer, as they:

- control the amount of spray (gallons per acre)
- determine the uniformity of the application
- affect the coverage of the target
- influence the drift potential

Most nozzles on strawberry sprayers are usually hydraulic nozzles, but some are air-shear types.

Hydraulic nozzles regulate spray flow by the size of the orifice (opening) and the pressure at the nozzle. Hydraulic nozzles atomize liquid spray mix by using pressure to force the liquid through the orifice. With enough speed and energy, the liquid breaks up into droplets when discharged against the atmospheric pressure. High pressures and small orifices form small droplets (which provide better coverage but are subject to drift), while low pressures and large orifices form large droplets (which provide poorer coverage but are less prone to drift).

Droplets are discharged from the nozzle tip in some specific pattern, depending on the design of the nozzle. With air-assist sprayers, the droplets are injected in front of or into an air stream and carried to the target. With a handgun or conventional boom sprayer, the speed built up at discharge must carry the spray droplets to the target.

Several types of hydraulic nozzles can be used to treat strawberry production areas. The type of nozzle used depends on the pest control situation, the target size, and drift concerns (Table 11-2). Each nozzle type (except the even flat fan nozzle) requires overlap with adjacent nozzle spray patterns for uniform application.

Table 11-1. Characteristics of different pump types.

	Pump Type		
Pump Characteristic	**Centrifugal**	**Piston**	**Diaphragm**
Materials handled	Any spray solution	Any spray solution	Most spray solutions; some chemicals may damage diaphragm
Pressure ranges (psi)	1–75 (single stage) 1–200 (multistage)	Up to 1,000	Up to 700
Flow rates (gpm)	1–120	2–60	1–60
Operating speeds (rpm)	2,000–4,000	600–1,800	200–1,200

Table 11-2. Different nozzles are used for different types of application materials.

	Nozzle Type				
Application	**Flat Fan**	**Even Flat Fan**	**Hollow Cone**	**Flooding Fan**	**Twin Fan**
Herbicides					
Soil-incorporated				Good	
Preëmergent	Good	Very Good			
Postemergent contact	Good	Good	Very Good		
Postemergent systemic	Good	Very Good			Very Good
Fungicides					
Contact	Good	Good	Good		
Systemic		Very Good			
Insecticides					
Contact	Good		Very Good		Very Good
Systemic		Very Good			

Adapted from R. Grisso, S.D. Askew, and D. McCall (2019), Virginia Cooperative Extension Publication 442-032.

The **flat fan nozzle** is a good general-purpose nozzle for broadcast spraying (Figure 11-3). Flat fan nozzles are generally used for herbicide or insecticide applications where deep foliage penetration is not required. Spray distribution is influenced by the nozzle spacing, nozzle height above the target area, and angle of the spray pattern (Figure 11-4). Nozzles should be slightly slanted so that adjacent patterns do not interfere with each other.

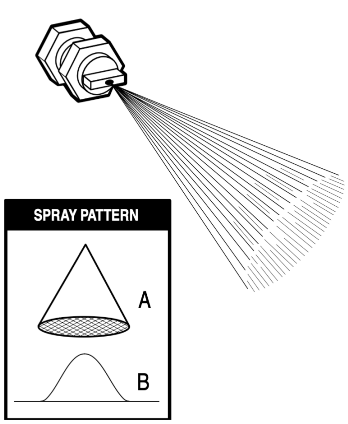


Figure 11-3. Flat fan nozzle spray pattern (A) and spray distribution (B).

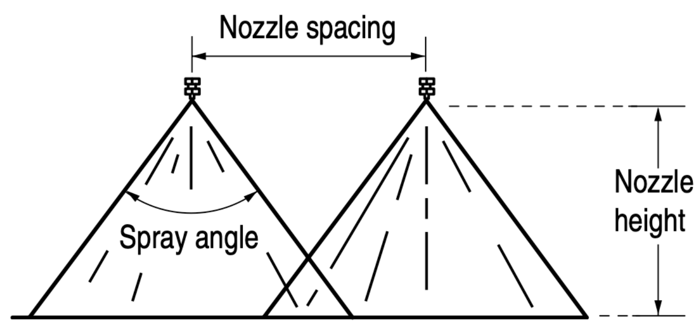


Figure11-4. Setup of flat fan nozzles.

The spray stream from a regular flat fan nozzle has an ellipsoid shape: it forms an oval pattern on the ground under the nozzle. Regular flat fan nozzles are available with operating pressures of 30–75 psi. Generally, flat fan nozzles produce a wide range of droplet sizes, including many small and large droplets. The percentage of small droplets decreases as the operating pressure decreases. Flat fan nozzles should be operated within their recommended operating pressure range to avoid distorting the spray pattern. Flat fan nozzles can produce different spray angles. **Wide-angle flat fan nozzles** produce smaller droplets than regular flat nozzles at the same flow rates. However, they can be used closer to the ground than regular flat fan nozzles, which reduces the drift hazard. **Extended-range fan nozzles** are designed to provide similar spray patterns over a wide or extended range of pressures (15–60 psi). The extended range nozzle should be used in situations where nozzle pressure is adjusted significantly during normal sprayer operation; for example, when large pressure changes are made to change nozzle output. **Low-pressure flat fan nozzles** are designed to provide the same spray distribution characteristics as other flat fan nozzles while operating at pressures under 20 psi. These nozzles produce a spray of fairly large droplets that are less susceptible to drift.

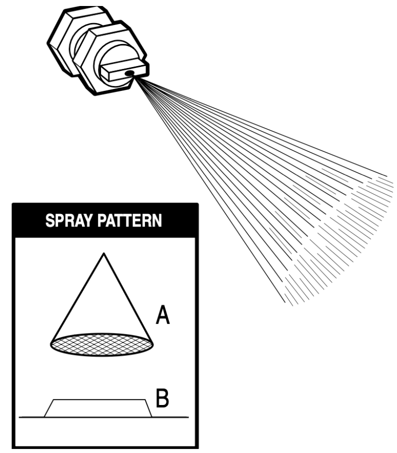


Figure 11-5. Even flat fan nozzle spray pattern (A) and spray dostribution (B).

Even flat fan nozzles are similar to regular flat fan nozzles, but apply a more even volume of spray material across the spray pattern (Figure 11-5). They are designed for applying spray solution in a band or narrow strip under the nozzle and do not need to be overlapped with other nozzles (Figure 11-6). Even flat fan nozzles generally produce a wide droplet spectrum that includes many small and large droplets. The width of the spray band can be changed by raising or lowering the nozzle height. Increasing the operating height of the even flat fan nozzle increases the effective spray width. Increasing the width of the spray band decreases the effective application rate because the same volume of spray is spread over a larger area. Even flat fan nozzles have operating characteristics, such as droplet size, similar to those of regular flat fan nozzles. They are designed for use at pressures below 60 psi.

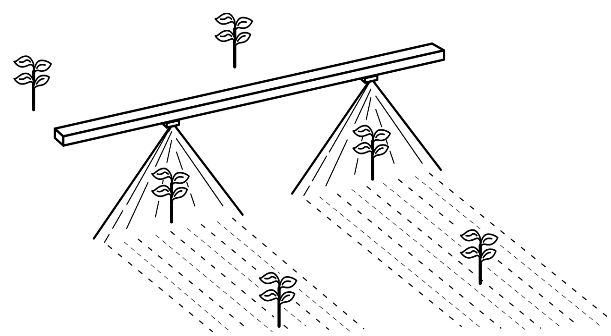


Figure 11-6. Band spraying with even flat fan nozzles.

Hollow cone nozzles produce a spray pattern where the liquid is concentrated on the outside of the conical pattern (Figure 11-7). More of the spray material is deposited on the edges of the hollow cone spray pattern with less directly under the nozzle. One- or two-piece hollow cone nozzles are available from manufacturers. Two-piece cone (disc and core) nozzles are available with operating pressures from 20–500 psi and usually with higher flow capacities than one-piece nozzles. One-piece hollow cone nozzles are available with operating pressures from 40–120 psi and typically produce smaller droplets than other hydraulic nozzles at the same operating pressures.

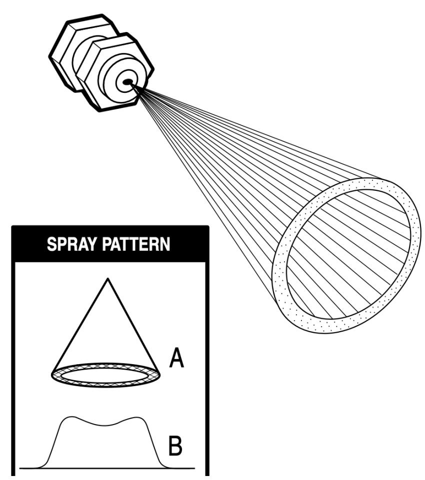


Figure 11-7. Hollow cone nozzle spray pattern (A) and spray distribution (B).

Hollow cone nozzles are best suited for applying materials like contact insecticides, fungicides, and growth regulators that require good spray coverage on the plant or target surface. Two or three low-volume hollow cone nozzles may also be used in a banding or directed spray operation, where the spray streams from the nozzles are directed around or at the same target (Figure 11-8).

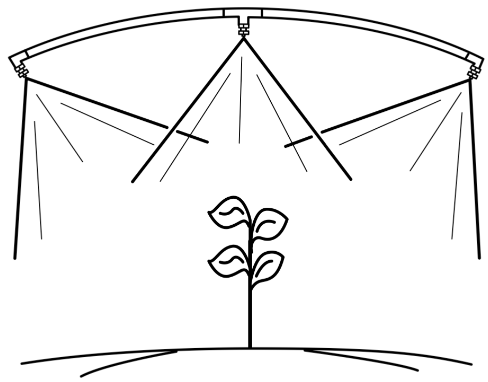


Figure 11-8. Directed spraying operation using hollow cone nozzles.

Flooding fan nozzles spray a stream of solution at a surface that breaks the stream into a wide pattern of droplets (Figure 11-9). The volume of spray produced is greatest directly under the nozzle and on the edges of the spray pattern. The nozzle, which operates at lower pressures of 10–25 psi, produces larger droplets than other nozzle types of similar capacities, and its large orifice resists plugging. The uniformity of the spray distribution and the droplet sizes that flooding nozzles produce at higher pressures are equivalent to those of regular flat fan nozzles.

Flooding fan nozzles are best suited to applying herbicides and fertilizer spray solutions in preëmergence broadcast or soil incorporation operations. They are generally not used when good spray coverage is required. Unless the spray pattern is deflected up into the air rather than down to the ground, the flooding fan nozzle produces very little risk of spray drift when operated at low pressures. Some research suggests that these nozzles can be operated at higher pressures to reduce the size of the spray droplets and improve spray coverage; increasing the pressure may also increase the size of the spray pattern. Changing the angle of the nozzle relative to the ground changes the size of the spray pattern. The nozzle position may have to be changed to compensate for pressure changes and ensure uniform spray distribution.

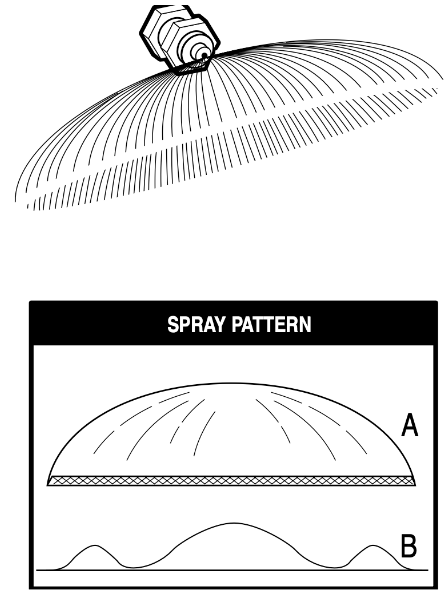


Figure 11-9. Flooding fan nozzle spray pattern (A) and spray distribution (B).

Twin fan nozzles operate as a regular flat fan nozzle but applies material through two orifices, thus producing two fan patterns (figure 11-10). Spray distribution from the twin fan nozzle is similar to that from the regular flat fan nozzle, where most of the spray is distributed directly under the nozzle. This nozzle is usually mounted so that 1 fan pattern operates forward in the direction of travel and 1 fan pattern operates away from the direction of travel. The twin fan spray pattern allows targets to be treated from different directions, thus improving spray coverage. Different twin fan nozzles are available with two spray streams set at different angles. The recommended spraying pressure is 30–60 psi.

Twin fan nozzles should be used with caution since they apply half of the spray volume of a regular fan nozzle out of each orifice. They produce more small droplets than a regular flat fan nozzle applying the same flow rate of spray solution. Finer screens or strainers should be used with these nozzles to prevent plugging of the small orifices. Twin fan nozzles are best suited for application of contact pesticides that require good spray coverage. The twin fan spray pattern improves spray penetration through dense foliage and crop residue.

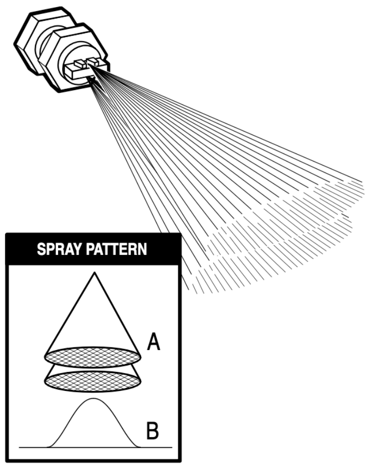


Figure 11-10. Twin fan nozzle spray pattern (A) and spray distribution (B).

Air-shear nozzles use a high-speed air stream to break the liquid into droplets; thus, these nozzles are limited to sprayers with a high-velocity air discharge. Depending on the nozzle configuration and injection angle, air speeds of 170–400 miles per hour (mph) are required. Discharging the spray directly into the air stream against the air flow produces the smallest droplets; at 90° to the air stream, intermediate droplets; and with the air stream, the largest droplets.

Air-shear nozzles operate at low pressures, often in the 15–35 psi range, which results in slow wear rates for the nozzles and the pump. While air-shear nozzles have large openings that minimize plugging, they are more difficult to calibrate/adjust than hydraulic nozzles. They are most commonly found in airblast sprayers, but some backpack sprayers have this type of nozzle.

Nozzle Life

As a nozzle wears, its performance deteriorates. The orifice enlarges, which increases the flow rate. As a result, atomization may change, which in turn changes droplet size as well as the distribution of droplet sizes. Wear will also distort droplet distribution patterns.

For long-lasting nozzles, select those made of materials that resist wear and corrosion. Sprayer tips can be made from brass, nylon, plastic, stainless steel, hardened stainless steel, tungsten carbide, or ceramic materials. Brass tips are the least expensive, but the metal is soft, and the tips wear rapidly—especially with abrasive sprays such as wettable powders. Nylon tips cost about the same as brass but wear better. Plastic tips tend to last longer than nylon but not as long as stainless steel, and they wear inconsistently. Stainless steel and hardened stainless steel tips cost more but wear much better—in the long run, they can be bargains. Stainless steel tips resist abrasion and corrosion and are recommended for applying wettable powders. Tungsten carbide and ceramic tips are very long-lasting but are not available for all sprayers.

Nozzle Size

After selecting a nozzle type, determine which size or flow rate is needed. Typically, only 1 nozzle size should be used across the sprayer. Nozzle sizes should be selected based on the travel speed (mph) of the sprayer and the width of the area treated by each nozzle, to provide the desired application rate (gallons per acre). The total required flow through each nozzle can be calculated with this equation:

Calculating required flow

Flow per nozzle (gallons per minute) = gallons per acre x mph x width / 5,940

Definitions:

- Miles per hour = mph
- 5,940 = a constant to make units consistent
- Width = nozzle spacing (in inches) for broadcast spraying;

  OR = spray width in inches of one band nozzle;

  OR = row spacing (in inches) / number of nozzles per row in directed spraying

For example: To apply 100 gallons per acre at a driving speed of 3 mph with a broadcast sprayer using nozzles spaced on 20-inch centers, the required total flow through each nozzle is: 100 gallons per acre x 3 mph x 20 inches / 5,940 = 1.01 gallons per minute

Once the required nozzle flow rate has been calculated, consult nozzle manufacturers' catalogs to select the nozzle that provides the required output within the operating pressure range of the sprayer. Changing the pressure changes the nozzle flow rate, but adjusting the pressure affects spray droplet size and drift as well as the spray pattern. To adjust flow rate, change nozzles instead of changing operating pressure. Pressure must be increased4 times to double the nozzle flow rate, and the change in pressure significantly affects nozzle performance.

Nozzle manufacturers specify how to set up their nozzles to provide a uniform spray distribution. The instructions vary by nozzle type, size, and manufacturer, so different nozzle types should not be mounted on the same boom. Manufacturers code nozzles by type, flow rate, fan angle, operating pressure range, and nozzle material. Each manufacturer has its own codes and descriptions, so it is important to know the meaning of codes when comparing nozzles or selecting replacements. Consult nozzle manufacturers' catalogs to determine the best operating parameters, such as pressure, height, and spacing, for specific nozzles.

Air Delivery Systems

As mentioned previously, some newer boom sprayers are incorporating some form of air system to aid in delivery of spray to the target area. Some air-assist sprayers will direct a sheet of air behind the nozzles. Others will direct air around the nozzle.

Air-assisted boom sprayers have been shown to provide many advantages over traditional boom sprayers. When the air system is properly adjusted and matched to the nozzles, it is possible to increase penetration to denser parts of the canopy, increase coverage on under leaf surfaces, and reduce spray drift. However, in some situations, especially when treating bare ground or small plants, the spray can bounce back up into the air and increase the risk of spray drift. With some air-assist sprayers, the operator can adjust the air speed to better match the canopy conditions and the delivery needs. Some sprayers can be adjusted with regard to the direction of air flow. Directing air and spray at an angle has been shown to increase penetration and distribute spray more uniformly throughout the canopy.

Preparing the Sprayer for Work

Be it early-season, mid-season, or mid-winter, time spent maintaining a crop sprayer is never wasted. Surveys have shown that many farmers are using inaccurate sprayers. Faulty sprayers contribute to increased drift levels and waste money through inefficiency and overuse of chemicals.

Sprayers must be regularly examined to ensure that they have been properly maintained and that they have no outstanding repairs. Before attempting any work on a machine, make sure that it is fully supported on stands, that it has been thoroughly cleaned, and that all necessary protective clothing is on hand.

The cost of good maintenance is soon recovered. For example, replacing a faulty pressure gauge that has been reading 15% below the actual pressure may pay for itself in about 2 hours of operation. Maintenance measures such as fitting a new set of nozzles at the beginning of each season will also save money. Even when there is as little as 5% overapplication, the cost of a new set of nozzles would be recovered in less than a day's work.

CAUTION:

- Take great care when adjusting a sprayer while the tractor engine is running.
- Engage the handbrake whenever leaving the tractor seat.

Sprayer Operation

Factors important in sprayer operation include tractor selection and operation, drift control, pump pressure, and driving speed. Practice sprayer operation with only water in the tank until you are completely familiar with all controls and procedures. All of the tractor's external services—hydraulic, electrical, and pneumatic—must be clean and in good working order. Tractors fitted with cabs must have efficient air filtration systems. All protective guards must be in place. Trailer-mounted sprayers are often close-coupled to the tractor, so it is essential that the drawbar and the PTO shaft are correctly adjusted for turning. PTO shafts must be disengaged when making very tight turns.

Pump pressure influences the droplet size produced by hydraulic nozzles. Increased pressure may improve coverage by producing more droplets, but these smaller droplets increase drift potential. Increasing pressure may not necessarily increase the speed of droplets or penetration into the canopy, since smaller droplets have less momentum. With air-shear nozzles, the pump creates only the flow, not the atomization, so a fairly low pressure will generate a smooth flow through the flow regulators. Always operate a pump within its designed pressure range and according to the manufacturer's recommendations.

Travel speed may also affect spray coverage. As ground speed increases, the effective distance to the target increases. Higher travel speeds result in more bouncing and swaying, which also cause more distortion of the spray pattern and less uniform spray distribution. Increasing travel speed generally requires the use of larger orifice nozzles to produce higher output and maintain the desired application rate. Higher output nozzles produce larger droplets, which will reduce spray coverage.

Sprayer Calibration

Calibrating a sprayer means making a "check" or trial run to determine the actual application rate with the selected nozzles, pressure and travel speed. Sprayers should be calibrated before new nozzles are used for the first time and whenever pressure or speed is adjusted. Calibration takes only a few minutes and is time well spent. It is necessary to determine the actual application rate of the sprayer in the field because:

- Chemicals must be applied at the proper rates to be effective and economical. Using more chemical than needed is wasteful and may exceed labeled rates; not using enough can be ineffective and wastes expense for materials and labor.
- Nozzle catalog values are based on pressure, travel speed, flow rate, and row or nozzle spacing. An inaccurate pressure gauge or speedometer, wheel slip, friction loss in the plumbing, or other factors may result in nozzle performance not matching catalog values.
- An operator must know the application rate to add the correct amount of chemical to the tank.

Precalibration

Before calibration, check that the sprayer is operating properly:

1) Check and clean all nozzles and screens. Replace any that are damaged.

2) Observe nozzle patterns; they should be continuous and smooth with no skips or heavy streams. Replace any nozzles that are suspect. If more than 1or 2 need replacing, probably all need replacing.

3) Check the nozzles and their arrangement on the boom for proper spray pattern overlap. Follow manufacturer's recommendations. Are they the proper distance apart on the boom? Will they be at the correct distance from the crop (height) during sprayer operation?

4) Check the pressure gauge. Pressure should be stable at the desired level while spraying. If the gauge fluctuates due to pump pulsations, install a damper between the line and the gauge or use an oil-damped gauge. The gauge will be easier to read and will last longer.

Determining the forward speed of the sprayer

Mark out a course that is at least 250' long with a stake at each end. Using a stopwatch, record the time it takes to drive the course at normal spraying speed. The sprayer should be filled half-full of water to get an accurate speed. Record tractor engine revolutions and gear selected.

$$\frac{\text{Feet traveled}}{\text{Time traveled (seconds)}} \times \frac{60}{88} = \text{mph}$$

Boom Sprayer Calibration Procedure

	Your Figures	***Example***
Nozzle type on your sprayer (all nozzles must be identical)		110 04 flat fan
Recommended application volume (From manufacturer's label)		20 gpa
Measured sprayer speed		4 mph
Nozzle spacing		20 inches

Step 1. Determine the forward speed of the sprayer (see above) in mph.

Step 2. Record the following information.

Step 3. Calculate the nozzle output that you should be getting (gallons per minute).

Gallons per minute = (gallons per acre x mph x nozzle spacing) / 5940

Example: Gallons per minute = (20 x 4 x 20)/5940 = 1600/5940 = 0.27

Step 4. Measure actual nozzle output. Set the correct pressure at the gauge using the pressure regulating valve. Collect and measure the output of each nozzle for 1 minute.

Step 5. Compare required output values to actual nozzle output values. The output of each nozzle should be approximately the same as calculated in Step 3 above. Remember that there are 128 fl. oz. in 1 gallon. If output has been calculated in gallons per minute then output is multiplied by 128 to determine ounces used per minute. Replace any nozzle tips that are less than 90% accurate.

Spraying Equipment for Small Plantings

Although powered sprayers make strawberry spraying easy and fast, they are relatively expensive and must be used on considerable acreage to be economically justified. This acreage may include strawberries or other crops, but the fixed (ownership) costs must be spread over many acres for even smaller units to be feasible. Growers with smaller plantings will need to explore alternative, less expensive spraying equipment.

Hand-Held Sprayers

Hydraulic hand-held sprayers are "handgun" sprayers that may be equipped with single or multiple nozzles (Figure 11-11). The multiple nozzle guns are actually miniature hand-held booms. Handguns are connected by a relatively long hose to a powered pump. Most handguns require high pressure, so typically either piston or diaphragm pumps are used. As with any hydraulic nozzle, the principle of handgun operation is that pressure is used to atomize the spray liquid into droplets. The energy of the droplet's velocity at the nozzle discharge projects the spray to the target. The farther the target is from the handgun, the higher the pressure needed to provide enough velocity to carry droplets to the target. However, as pressure increases, droplet size decreases, and smaller droplets tend to slow down more quickly.

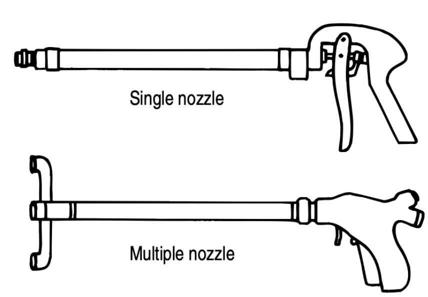


Figure 11-11. Examples of hand-held sprayers.

Handgun spraying is often a two-person operation, with one person operating the handgun and the other driving the vehicle used to transport the sprayer through the field. This is convenient but increases labor needs. The quality of handgun spraying depends on the operator: to spray at a uniform rate with enough coverage for adequate pest control requires practice and skill.

Factors such as temperature, fatigue, slope of the terrain, walking surface, and length and weight of the hose can increase the difficulty of handgun spraying.

Backpack Sprayers

Another sprayer suitable for small plantings up to about ¼ acre is the backpack sprayer (Figure 11-12). They are also useful for making spot treatments where the pest problem is not spread across the entire field. This sprayer is manually operated and is carried on the operator's back with shoulder straps. Sprayer parts include the basic parts of most sprayers: a tank to hold the spray mix, a pump or pressurized gas canister to produce pressure and flow, controls to regulate flow, and an atomizer.

Tanks are typically plastic or steel and in the 3–5 gallon size range. Some have a mechanical agitator that moves when the pump is used to provide some mixing; others may have jet agitation. Before spraying, the entire sprayer can be shaken to ensure good mixing.

Hand pump sprayers have a built-in piston or diaphragm pump. Some models can be adapted to either left- or right-handed pumping, with the free hand operating the flow control valve and the nozzle. Some models have battery-powered pumps. The pumps are positive displacement types and can produce relatively high pressures. There is only a very small chamber where the liquid is under pressure, making the sprayer a "pump-as-you-go" system.

The distribution system includes an on/off valve, usually with a pistol-grip handle, and one or more nozzles. The nozzle is often mounted at an angle on a 16- to 20-inch wand to aid spray placement on the plants. Some designs provide for interchangeable nozzle tips so that nozzles can be better matched to the job.

Using a backpack sprayer to spray strawberries is a time- and labor-intensive method. From the standpoint of equipment investment, the cost is low, but the capacity is also very low. However, where labor is a minimal consideration, such as for many homeowners and hobbyists, the backpack sprayer is effective if properly used.

Since the operator controls the travel speed, variations in application rate similar to those caused by handgun systems can be expected. In addition, extra care should be given to coverage and uniformity because so little water is used as the spray mix carrier and diluent. It is not practical to apply a rate close to 100 gallons per acre with a hand sprayer.

Powered Backpack Sprayers

Another version of the backpack sprayer has a very small engine and fan to create an air-assist backpack sprayer. This sprayer is also known as a motorized backpack mist blower.

Powered backpack sprayers are equipped with 3–5 horsepower engines. Two-stroke cycle engines are used to minimize weight; however, they require a gasoline/oil mixture for fuel. Operators should follow the manufacturer's recommendation on the oil-to-fuel ratio, which may be given on the fuel tank or its cap. The engines operate at 5,800–8,000 rpm and are noisy; operators should wear ear protection. The sprayers are much heavier than manual models, weighing 17–25 lbs when empty.

The engine operates a centrifugal fan that delivers 200–450 cubic feet of air per minute. The discharge velocity is usually over 200 mph. With this high velocity, air shear nozzles are practical and often used. Hydraulic orifice and rotary nozzles are also used to form and inject droplets into the air stream. The air from the fan is fed through a flexible tube with an air nozzle on the end. The operator controls the direction of the air stream to place the spray on the target. Because of the high discharge velocity, the air nozzle should be at least 6 feet from plants. The air stream should be aimed downwind so that natural currents assist in dispersing droplets away from the operator. Spraying into even a slight wind may result in droplets being blown back onto the operator. Care should be taken to avoid over spraying the target, since it is more difficult to observe the spray coverage produced by these sprayers.

Motorized backpack mist blowers can spray strawberries much faster than manual sprayers. The air stream will assist in delivery and coverage, even at lower application rates. However, the area that can be sprayed is still limited, because the sprayer tanks are about the same size or even smaller than those on manual sprayers to minimize the weight of the unit. Therefore, a tankful will cover only a relatively small area, and it is time-consuming to refill the tank and measure chemicals.

Hand Sprayer Calibration

Hand sprayers need to be calibrated for the same reasons as power sprayers. The operator must first determine the percentage of an acre covered by one tankful of spray mix. By multiplying this percentage by the recommended application rate per acre, the operator can easily calculate the amount of chemical required per tank. Before calibrating a sprayer, operate it with only water to be sure all parts are properly working.

Handguns, manual backpacks prayers, motorized backpack sprayers, and other hand sprayers can be calibrated with the following method:

Step 1. Select a calibration plot (row length) that represents 1/100 to 1/20 of an acre. A bigger plot will produce more accurate results. Assuming rows are 4 feet wide, 1/100 of an acre has approximately 109 row-feet; and 1/20 of an acre has approximately 545 row-feet.

Step 2. Fill the sprayer tank with only water, mark the level, and spray the calibration plot at a rate that achieves good plant coverage. This requires good judgment; an inexperienced operator should get help or training from an experienced or trained pesticide applicator. The goal is to provide coverage to the entire plant without reaching the point of runoff (spray mix dripping from plants) to avoid waste and potential pollution.

Step 3. Measure the amount of water required to refill the sprayer tank to the previous level. Calculate the application rate by dividing the amount of water used by the area covered. For example, if 1.5 quarts were applied to 1/100 of an acre, the actual application rate is 150 quarts, or 37.5 gallons per acre.

Hand sprayers necessarily place the operator near the nozzles and discharge point of the sprayer. This makes operator protection very important. Basic protection includes a hat, long-sleeved shirt and trousers, or a spray suit. Depending on the toxicity of the chemicals, other protective gear such as a respirator, goggles, waterproof gloves, or waterproof boots may be needed. All operators should read the labels and follow directions for the specific material being applied. The spray should be discharged with the wind so that droplets are carried away from the operator. If spray is directed into the wind, some will be blown back onto the operator.

Drift can be a problem with hand sprayers and may be even more important where lower application rates are used. The spray mix is more concentrated, so any loss means more active ingredient is lost. The best solution is to spray only when winds are slight or blowing at less than 5 mph. Operators should use as low a pressure and as large an orifice as is practical to minimize the number of small droplets formed. Adding a drift control additive to the spray mix may also be helpful.

Hand Sprayer Operation

Hand sprayers require much more labor to operate than the tractor-powered units, so hand sprayers are limited to small plantings. High application rates similar to those achieved with the powered sprayers are feasible with the powered handgun, because the spray mix is carried by a tractor or trailer and the pump is powered. However, with backpack sprayers it is not practical to use such high rates.

A major problem with hand sprayers is that a human operator cannot walk along a row at a uniform rate. Variation in walking speed will affect the application rate.

However, a benefit is that an experienced applicator may be able to compensate for variations in plant density. For example, if a row is missing a plant, the operator can skip that space and move immediately to the next plant. Inexperienced operators should practice with water until they can apply a pesticide uniformly at the recommended rate.

Sprayer Maintenance

Like all other equipment, sprayers must be kept in good working order to last a long time. Cleaning is especially important because of the chemicals used. A very thorough cleaning should be performed whenever chemicals are changed and at the end of each spraying season. Sprayers must be protected from corrosion and freezing in storage during the off season.

Cleaning

Sprayers must be cleaned to prevent corrosion, cross contamination of pesticides, and crop injury. Trace amounts of one pesticide can react with another or carry over to the next spraying and cause damage. Long exposure to even small amounts of some pesticides can damage sprayer parts, even stainless steel tips and fiberglass tanks. If crops are sprayed that are sensitive to the herbicides used, maintain two sprayers—one for herbicides and one for all other spraying. No cleaning method is perfect, but careful cleaning will remove all but insignificant amounts of insecticides and fungicides.

Always try to end the day or a spraying job with an empty tank to avoid having leftover spray mix. Be careful when disposing of leftover mix or wash water; avoid contaminating water supplies and injuring plants or animals. Do not leave puddles that might be accessible to children, pets, farm animals, or wildlife. Two recommended methods of disposal are collecting the waste in a holding tank and recycling it during the next spraying, or spraying waste on another area with similar plants and problems while being careful to avoid overapplication.

When the sprayers are empty, triple rinse the tanks with clean water, preferably after each day's operation. Also rinse the outside of the sprayer. Before changing pesticides or storing sprayers for the winter, clean sprayers thoroughly with a cleaning solution. Check the label for directions. A good detergent solution will remove most insecticides and fungicides. First, flush the tank with water; then add the cleaning solution to the tank and thoroughly agitate it before flushing again. Always flush with clean water to remove the cleaning solution.

Remove nozzle tips and screens and clean them in a strong detergent solution or kerosene using a soft brush such as an old toothbrush. Follow the same safety precautions during cleaning as for mixing and application. Use a respirator, waterproof gloves, or other protective gear as directed by pesticide label instructions.

Lubrication

Lubrication may be required depending on the sprayer design. Some sprayers are built with sealed bearings that do not require additional lubrication. Wear points other than bearings may need to be greased or oiled. Some sprayer parts may need to be coated to prevent corrosion during nonuse periods. Follow the instructions in the owner's manual.

Winterizing

Sprayers must be protected from corrosion and freezing during winter storage. If a sprayer has no rubber parts such as gaskets, diaphragms, or hoses, put new or used engine oil from a gasoline engine in the tank before the final flushing to prevent corrosion. As water is pumped from the sprayer, the oil will leave a protective coating inside the tank, pump, and plumbing. If the pump has rubber parts, disconnect the lines and put automotive antifreeze or radiator rust inhibitor in the inlet and outlet ports. If the pump has no rubber parts, engine oil is satisfactory. Rotate or move the pump several times to completely coat interior surfaces.

Remove nozzle tips and screens and store them in a can of light oil such as diesel fuel or kerosene to prevent corrosion. Close nozzle openings with duct tape to prevent dirt, insects, or mice from entering. During the final cleaning, inspect the hoses, clamps, connections, nozzle tips, and screens for possible replacement. Store the sprayer in a clean, dry building.

Operator Safety

When handling concentrate or dilute pesticide, always wear the protective clothing specified on the product label, which may include:

- Face shield
- Respirator or Particle mask (change as recommended by manufacturer)
- Coverall (one or two piece)
- Trousers
- Hood
- Gloves
- Boots

Make sure that you have access to adequate washing facilities with soap and water and paper towels, a first aid kit, and access to an emergency contact by phone or radio.

Put on and take off protective clothing in an orderly manner avoiding contact with contaminated surfaces (figure 11-13).

Figure 11-12. Backpack sprayer.

At the end of each work period (e.g., before meal breaks), thoroughly wash the outsides of gloves in soap and water and wipe off surplus moisture, thoroughly wash down overalls, then wash hands thoroughly with soap and water and dry well. Always put on, remove, hang to dry, and store protective clothing away from sources of contamination, as well as restrooms and eating places, personal clothing, break areas or vehicles. Replace damaged items promptly, especially gloves.

On ↑		Off ↓
	Gloves	
	Respirator or Mask	
	Trousers	
	Boots	
	Jacket	
	Hood	
	Face shield	

Figure 11-13. Follow this specific order for dressing and undressing prior to and after a spray application.

CHAPTER 12

Harvesting, Handling, and Transporting Fresh Fruit

High-quality strawberry fruit has desirable color, size, firmness, flavor, and shape, and is free from defects. However, strawberries are one of the most perishable fruits, and these quality standards can be hard to achieve. Strawberries are susceptible to handling injury, water loss, fungal decay, and physiological deterioration.

Strawberry fruit has a high respiration rate and thus, short storage potential. Fruit ripens quickly in the field and even faster after harvest, especially at room temperature. For fruit to maintain flavor, glossiness, color, firmness, and be free of decay, special attention must be paid to several preharvest and postharvest factors. The importance of each of these factors will vary depending on how the strawberries are marketed. For example, storage life will be less important to a grower with a pick-your-own (PYO) operation, where growers supplying wholesale and retail markets that require longer postharvest periods must carefully manage fruit.

Preharvest Considerations

In general, firmer strawberry varieties have a longer storage and shelf life and are more resistant to decay than softer varieties. Other preharvest factors that affect fruit quality include growing site, plant health and nutrition, and pesticide applications. Fungicides applied during bloom and at petal fall can reduce unmarketable fruit yield caused by fungal pathogens. For example, gray mold (*Botrytis cinerea*) readily infects senescent petals, which transmit the mold into the developing fruit.

Growers should focus on creating microclimates that minimize preharvest disease pressure in the field. A lower plant density will increase airflow and reduce disease pressure on plants and fruit, and orienting rows parallel to prevailing summer winds will also benefit plants. Rain and dew increase the likelihood of fungal infections, but moisture will evaporate quicker in a sparse canopy with good air circulation than in a dense one. Ideally, fruit should not touch damp soil, and straw or plastic ground mulch can serve as a buffer. Similarly, proper irrigation management can minimize decay; irrigate early in the day so that there is ample time for plants to dry before evening. It is also important to maintain cleanliness and sanitation in the field.

Plant nutrition also impacts storage life, and foliar nutrient analysis can help fine-tune nutrient management plans. Fruit from plants that are nutritionally stressed will have a shorter storage potential than fruit from healthy plants. Plants must have access to adequate potassium and calcium, and nitrogen cannot be too high. There is a positive relationship between nitrogen availability and fruit softness, as well as susceptibility to gray mold infection. On the other hand, adequate calcium helps maintain cell wall structure and slows fruit ripening. Plant tissue testing can confirm calcium status so that deficiencies can be addressed. Preharvest calcium sprays have not been shown to improve shelf life or fruit quality[1].

Harvesting & Packaging

Timing

Strawberries are **non-climacteric**, which means that the ripening process is not controlled by ethylene production as with some other fruits, such as apples and pears. Strawberry fruit also do not store starch that can be converted to sugars after harvest. As a result, strawberry fruit will not develop good flavor if picked while immature, even though they will develop red color after harvest. Since field-ripened berries have shorter storage potential than partially ripe berries, there is a compromise between storability and quality: ripe fruit will taste better but have a shorter storage life, while fruit harvested before it is fully ripe will be less flavorful but will last longer in storage. Strawberry growers must time the harvest to balance the benefits of fully ripe fruit and fruit that meets U.S. quality standards, which only require that strawberries show ½ to ¾ pink or red color on the surface.

In a PYO operation, growers can prioritize field-ripened flavor since the consumer takes the fruit home immediately after harvest. However, when fruit handling and storage are involved (for different markets), producers need to strike a balance between firmness, color, and eating quality.

Picking and Handling

Strawberry fruit should be harvested gently. The susceptibility of fruit to bruising and other injuries varies depending on variety, maturity, and ripening stage. While bruising can be confused with decay, bruising appears as darkened, compressed tissue, whereas decay is marked by soft flesh that is easily scooped from the fruit.

Strawberry fruits are easily bruised or damaged by pickers, and damage caused at the time of harvest may not be visible until later. Bruising occurs when fingers pull too hard on the fruit, when the fruit falls on a rigid body, or through contact with other fruit. Studies in California have found that pickers vary widely in the percentage of fruit they damage; thus, pickers must be properly trained to minimize fruit damage. Rough treatment during transport can also cause bruising. Most fruit is harvested by holding the fruit and lightly pulling away from the plant, though tilting the fruit to one side will help the pedicel detach from the peduncle with less pulling required. Some specialty high-value strawberries are clipped using scissors, leaving attractive long stems.

Pathogens that cause fruit decay can be transferred from infected fruit to healthy fruit during picking, and because of this, pickers must be aware of contamination. Ideally, some pickers should be designated to only remove infected, damaged, and overripe fruit. In practice, providing gloves to pickers and instructing them to change them at a particular point, including after touching diseased fruit, may may be the most realistic approach for reducing pathogen spread. It is important to remove diseased fruit from plants during picking. Removing such fruit from the field altogether is best, as leaving overripe or infected fruit in the field increases the disease pressure from gray mold, leather rot, and anthracnose, and pest pressure from strawberry sap beetle, slugs, and spotted-wing drosophila. Ideally, diseased fruit would be buried or burned when removed from the field.

Be sure that workers are also trained on proper hygiene and other food safety practices to minimize the risk of contamination by foodborne pathogens (see Harvest and Postharvest Food Safety Considerations for Strawberry Farms). Food safety training must be conducted before workers begin harvesting produce on the farm.

Grading

Strawberry fruit is almost always packed in the field rather than graded on sorting tables. Packing in the field reduces how many times the fruit are handled, leaving fewer opportunities to damage fruit. However, postharvest grading does allow removal of damaged fruit (cuts, finger bruises, torn or removed calyxes) or decayed fruit that diminishes storability of the fruit around it. Grading also can ensure uniform maturity, which is important if storage is required—thus, it may be useful in some situations.

Strawberry fruits that have been harvested at similar maturity (color) are more likely to respond to postharvest treatments/conditions in a uniform manner. Conversely, fruit of a variety of ripeness stages will not respond uniformly. Unripe fruits are slow to ripen, while the overripe ones lose their glossy appearance and become susceptible to decay. The overripe fruit can also become inoculum sources for diseases that will infect the other fruit. A mixture of ripeness stages is usually seen as unattractive in the marketplace.

Harvest and Postharvest Food Safety Considerations for Strawberry Farms

Worker training, hygiene, and postharvest sanitation are essential to farm food safety. Hygiene and cleaning practices can also reduce incidence of plant disease and improve the storage life of your strawberry crop.

Worker Training

Field workers that are harvesting fruit should receive training prior to working with fresh produce. Training should cover the following practices:

- Washing hands using potable water and soap prior to any contact with the crop, particularly after using the restroom, eating, smoking, or touching animals.
- No eating, drinking, or smoking in the berry field.
- No handling produce while ill.
- No harvesting fruit for market that are visibly contaminated with feces or have other evidence of contamination(rodent chew marks or bird pecks, etc.).

Provide workers with facilities and tools to support food safety practices. Provide easy access to restroom and hand washing facilities with potable running water for harvest workers. Designate an eating and drinking area outside of the berry field.

Records should be kept to document worker training. These must include the topic of the training, employee name, date, farm information, and signature of supervisor. Refresher trainings should be conducted as needed during the harvest season to ensure that food safety and proper harvesting practices continue to be followed.

Postharvest Sanitation

Clean harvest containers, tools, and transportation conditions are essential for avoiding contamination between the field and the consumer.

- Clean and sanitize reusable harvest trays between uses or as needed.
- Do not reuse single-use berry containers returned from customers that cannot be cleaned and sanitized (i.e., pulp, wooden, and plastic quart or pint containers, cardboard boxes, etc.)
- Maintain a clean and orderly postharvest packing area: sweep floors and remove culls, manage rodents and other pests inside buildings, clean and sanitize food contact surfaces.
- Prevent condensation and standing water in cold storage rooms.
- Inspect and clean truck beds and vehicles for safe transportation to markets.

Many extension and government resources are available to assist farms with worker training in multiple languages, planning for postharvest cleaning and sanitation, record-keeping, and more.

Packaging

There is a diversity of containers that can be used to market strawberry fruit and each type has advantages and disadvantages. Furthermore, certain markets may be accustomed to specific packaging. Ideally, shallow containers should be used to avoid compressing the fruit at the bottom from the weight of fruit above.

Photo 12-1. A variety of container options exist for fresh strawberries (E. Hodgdon).

Quart-sized containers are commonly used to sell in-season fruit in northeastern North America, but but pints are also used, especially for out-of-season fruit and specialty berries such as "pineberries". There are many container options for both sizes; photos 12-1 and 12-2 show just a few options. Pulp/fiber containers are inexpensive (10¢/quart) but stain easily and can hold moisture and easily tear. Wooden containers also stain and are about twice the price of fiber containers (20¢/quart), but are strong, natural-looking, and not necessarily disposable for the consumer. Open-weave pattern plastic quart containers ("boxes") are relatively sturdy and do not stain. These green plastic containers are common in eastern Canada, and are sometimes found in the northeastern US. Mesh covers ("caps") with elastic can be used to cover any of the open containers and prevent customers from handling berries. Covers are also available for plastic open-weave containers. Note that different quart containers hold significantly different quantities of fruit. Where fiber and wood quarts easily hold >1.5lbs (700g) of fruit (especially when mounded), plastic quarts are often closer to 600g (1.3 lbs). Be sure to take this into consideration when setting prices.

Solid clear plastic containers (clamshells) are popular among wholesalers and, unlike the open containers above, can be stacked. Clamshells are inexpensive, do not stain, significantly reduce moisture loss, and allow customers to examine berries from all sides. However, juice can accumulate at the bottom of the container, and it is thought to be more difficult to cool berries in clamshells. Furthermore, plastic containers may be inconsistent with the fresh-picked, natural image sought by many farm markets and stores, and customer preference is increasing toward selecting biodegradable materials versus plastic.

Customers should be encouraged to remove strawberries from the container at home, discard any damaged or decaying berries, transfer them to a covered container, and store fruit in the refrigerator to maximize the storage period of the remaining fruit.

Photo 12-2. Handle basket containers commonly used in eastern Canada (K. Orde).

Postharvest Handling

Storage life is the length of time in which the strawberry fruit is saleable. If properly cooled and stored, fruit should last 7 days at 32˚F. **Shelf life** refers to the length of time that strawberry fruit will maintain their quality at ambient temperatures (for example, at a roadside stand or market)—this is usually 1–2 days, with second-day fruit often sold as "day olds".

Postharvest fungicides are not used on strawberry fruit, but plant or bio-based postharvest coatings that improve storage life are the subject of current research and becoming commercially available.

Respiration

The respiration rate of strawberries is very high, comparable to that of other short-lived berries such as raspberries and blueberries, and much higher than that of apples (figure 12-1). Ripe strawberry fruit that are fully ripe also have higher respiration rates than less ripe fruit. However, there is a relationship between storage temperature and respiration rate, and prompt cooling and maintenance of proper temperatures and humidity are the most important actions a grower can take to maintain fruit quality. Each 10˚F reduction in storage temperature reduces the respiration rate of fruit by approximately 50%. For example, at 77˚F and 30% relative humidity, fruit will lose water 35x faster than at 32˚F and 90% relative humidity. Therefore, after harvest, a delay in cooling beyond an hour causes a dramatic reduction in the amount of marketable fruit. Fruit should not be left in the field exposed to direct sunlight, as they absorb radiant energy and can reach more than 10˚F above ambient temperatures. Containers should be shaded if they cannot be transported quickly to cold storage.

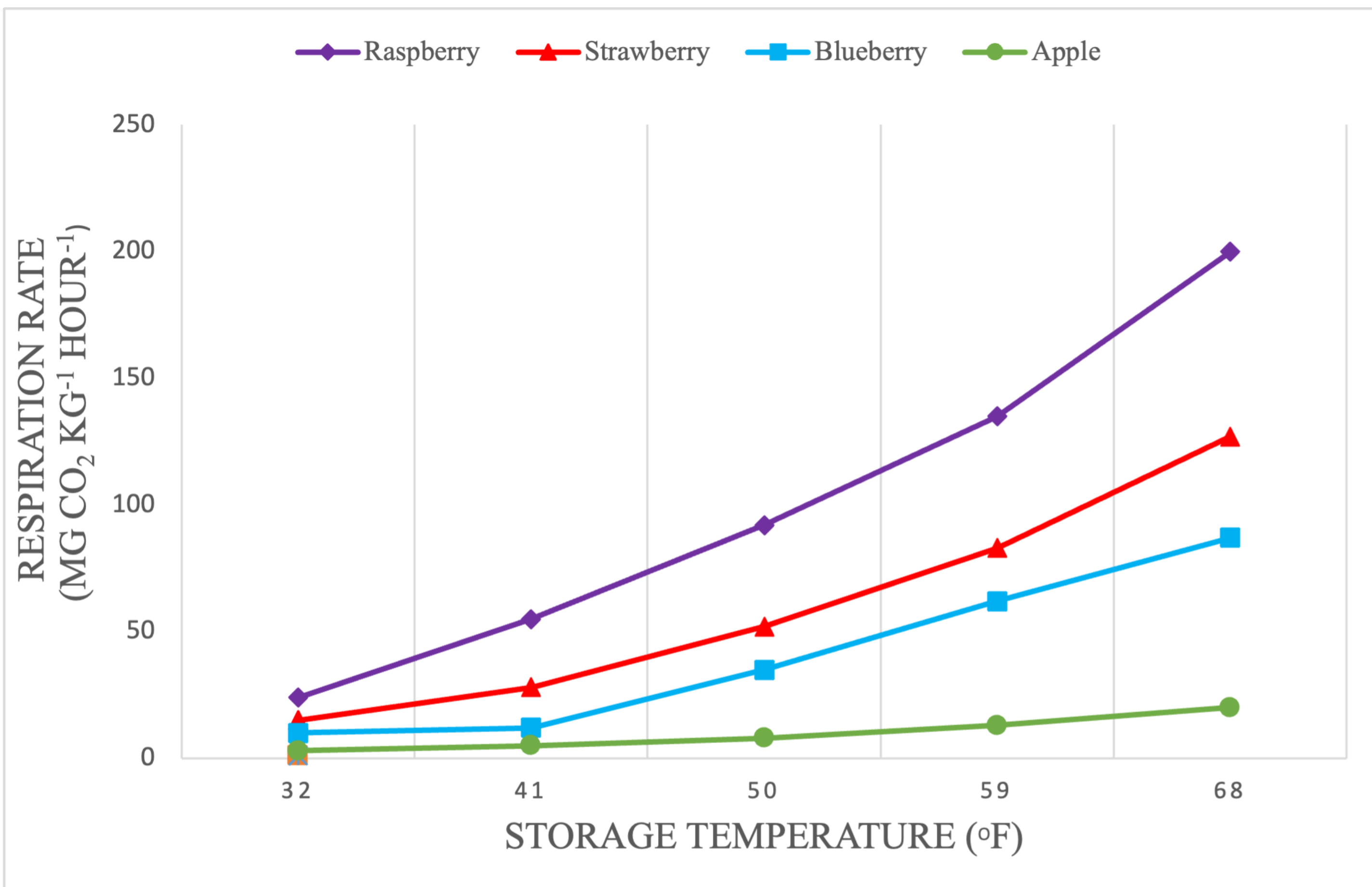


Figure 12-1. Respiration rates of raspberry, strawberry, blueberry, and apple fruits stored at different temperatures.

Temperature

Although 32˚F is the standard recommended temperature for strawberry storage, some growers have been reluctant to store berries at at a temperature this cold because of the probability of condensation when the fruit is removed from storage and exposed to warmer, more humid air. **Condensation** occurs when the fruit surface is colder and below the dew point of the air and water condenses on the fruit surface—much like a glass of ice water on a humid day. Condensation results in duller and less attractive fruit and promotes growth of micro organisms. There are many methods for reducing the likelihood of condensation. The best way is to maintain refrigeration during the entire marketing period; but this requires cold storage facilities for storage, transport, and display that many small producers do not have. Bringing cold fruit to display temperature using forced air-cooling systems that provide uniform air movement can help prevent condensation. Alternatively, growers may wrap flats in single use clean plastic film upon warming so that condensation will form on the plastic rather than fruit.

If one wishes to avoid condensation altogether, fruit can be harvested at the "white tip" stage and stored at 50˚F. Fruit ripened at this temperature have been shown to have higher antioxidant concentrations than fruit harvested at the red ripe stage. However, this higher temperature reduces storage potential, and fruit treated in this way may fare worse in warmer storage environments when organisms that cause decay are present.

The temperature in the storage room can be kept as low as 30˚F. Fruit will not freeze at or above this temperature because the sugars in the fruit lower the freezing point. Maintaining the storage at a slightly warmer temperature (32˚F) will allow some room for error.

Cooling Methods

Fruit temperatures can be reduced at the time of harvest by picking fruit early in the morning and moving harvested fruit to shaded areas. The cooler the fruit are when harvested, the less time it will take to bring them down to storage temperature.

Table12-1. Cooling rate of one 19-lb tray of strawberries in a passively cooled versus a forced air-cooled container.

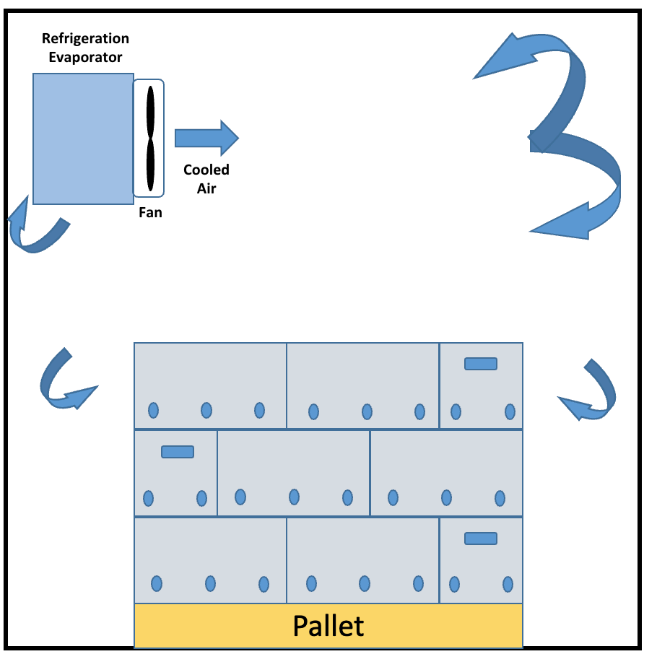
	Passive (room) cooled	**Forced air cooled**
Starting temperature	72˚F	68˚F
Temperature at 20 minutes	70˚F	59˚F
Temperature at 60 min.	61˚F	46˚F
Temperature at end of test (1hr 40min)	54˚F	44˚F
Observed cooling rate (˚F/min)	0.18 (linear)	0.24 (linear)
Time to ⅞ temperature (hrs)	5.0 (predicted)	1.5 (actual)

Adapted from: Callahan, C.W. and A. S. Chamberlin. 2020. Forced air cooling field trial results. University of Vermont Extension. The observed cooling rates are linear rates intended to capture the average rate over the test period. The 7/8 time for the forced air cooling test is as measured. The 7/8 time for the room cooling was predicted based on an exponential curve fit of the data from the test which was not run to completion for the room cooling method.

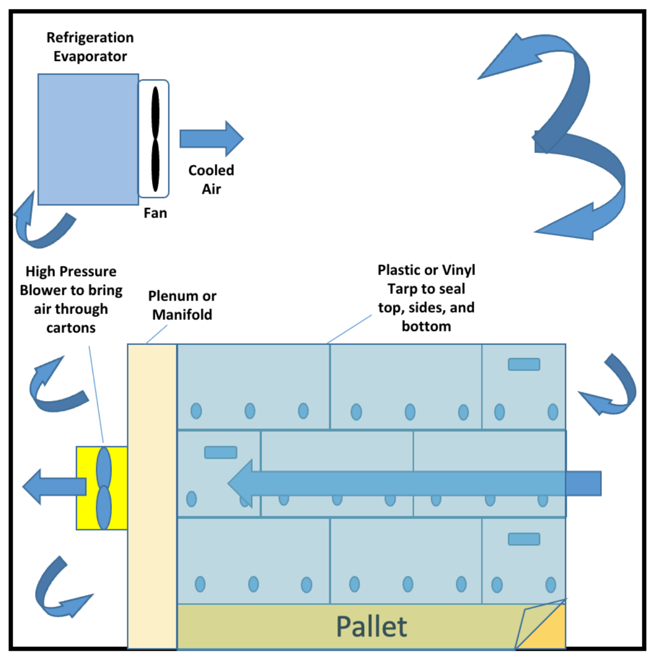
Once at the cold storage facility, fruit can be cooled by either passive (room) cooling or forced air cooling. **Passive cooling** is the most popular method in eastern North America. It is relatively slow but requires little equipment beyond cold storage facilities (walk-in coolers, CoolBots) and can be accelerated by spreading out boxes of fruit on a rack to expose all flats to the cold air circulated by the cooling unit. Care should be taken to maintain high humidity by optimizing evaporator sizing and refrigerant expansion valve settings, though a lower than necessary evaporator temperature will lead to excessively dry air. Once cooled, the flats can be stacked until the fruit is removed for sale.

Though less popular, **forced air cooling** is the optimal cooling method (table 12-1). Forced air cooling directs refrigerated air through a container holding the fruit (figure 12-2). Large-scale growers may have a separate forced air-cooling facility specifically designed for removing field heat, but inexpensive, effective improvisations can be adapted to any cold storage. There are free plans available for constructing a small to medium forced air cooler using basic materials and a blower that costs under $300 (see Further Reading and Citations).

The benefit of forced air cooling compared to passive cooling becomes evident when comparing the **⅞ cooling time**, which is how long it takes to remove ⅞ of the field heat. The typical ⅞ cooling time for passive cooling strawberries in 12-quart flats on pallets is 9 hours (540 minutes), while the ⅞ cooling time for forced air cooling is 90 minutes—6 times shorter. Using a small-scale countertop forced air cooler, researchers at the University of Vermont showed that for 19 lbs (1 plastic harvest tray) of freshly harvested strawberries, the average measured cooling rate was 1.3x faster using forced air cooling than passive cooling in a cooler set at 40˚F (table 12-1). This same test noted a ⅞ cooling time for the forced air cooling system of 1.5 hours, compared to a predicted ⅞ time of 5 hours for the for room cooling—3.3 times faster in the forced air system.



Produce packed in cartons, lugs, or other containers will not cool rapidly even when placed in a cooler. The cold air does not have sufficient velocity or pressure to pass into the center of the pallet or even to the center of a single carton, even when the containers have vented sides. Heat removal from the produce depends on conduction through produce and cartons which is slow.



Using a high pressure blower, cool air can be pulled through cartons of produce to remove field heat and reduce product temperature to storage temperature more quickly. The heat removal rate from the produce is enhanced due to increased convective cooling in addition to conduction. This lowers respiration and leads to improved quality.

Figure12-2. Room cooling (left) relies on passive air movement through stacked berry containers, and cools fruit slowly. Forced air cooling (right) uses fans to move air through a pallet of berries, and cools fruit at a faster rate. Adapted from: Callahan, C.W. and A.S. Chamberlin. 2018. Forced air cooling on the farm. University of Vermont Extension.

When operating a precooling system at any scale, the flesh temperature should be checked throughout the process using a needle probe thermometer to track the cooling rate of the fruit. The fan should be turned off when the flesh temperature is within 5˚F of the desired temperature to avoid dehydrating the fruit.

The choice of cooling unit has an important effect on the cooler operation and cooling process. If the temperature difference between the air and the cooling unit is too large, then ambient air moisture can condense on the evaporators and turn to ice, reducing humidity in the air. This drying of the air does not cause a problem for dry goods but will severely dehydrate fruit. The atmosphere around the fruit should be humid to prevent shrinkage, so a cooler should be able to maintain a relative humidity of 90–95% at 32˚F. These types of cooling units are more expensive and less common than those used for dry goods. Consult an agricultural engineering specialist for help with selecting a cooling unit and building a storage facility and be prepared to discuss your specific needs with your refrigeration contractor.

Hydrocooling, the process of treating fruit with cold water, has not been recommended in the past due to concerns over bruising fruit and fear of causing decay. However, research in Florida has shown that using chlorinated water for hydrocooling results in more rapid (10x faster) and uniform cooling of the fruit than forced-air cooling, and helps reduce fruit dehydration and microbial contamination[2]. With appropriate attention to hygiene, this method may be well suited for small-scale operations, although it is not a good choice for field packing scenarios.

Additional Technologies

High concentrations of carbon dioxide in storage and transportation, typically between 15% and 20%, will reduce fungal decay and help maintain strawberry quality. Some large shippers on the West Coast transport berries in a high carbon dioxide atmosphere to maintain quality. Pallet shrouds are injected with carbon dioxide before export. Selectively permeable membranes can be used to wrap the fruit in their individual containers. These membranes trap CO_2 and create a modified atmosphere surrounding the fruit. Excessive CO_2 levels will promote anaerobic fermentation and cause off-flavors in the fruit.

The scale of an operation needs to be large enough to make such a capital expenditure worthwhile, which likely precludes many growers in the eastern United States and Canada, especially those focused on retail. However, small portable units that can extend shelf life by several days are now available. Varieties differ in their tolerances to elevated levels of CO_2.

Several other technologies for extending strawberry storage and shelf life have been studied. Ethylene absorbers maintain fruit quality even though strawberry fruit do not produce appreciable amounts of ethylene. Skin coatings and other postharvest treatments are not easily applied in small operations common to the Northeast, but may change as new products are developed.

Respiration

An estimated 42% of strawberry fruit become un-marketable between harvest and the consumer due to decomposition and rot, with 14% loss occurring from farmer to wholesaler, 6% loss from wholesaler to retailer, and 22% loss from retailer to consumer. Much of these losses are due to poor handling after harvest.

As we’ve noted, many steps along the distribution chain can negatively affect fruit quality. Once fruit have been transported from the field and precooled, a typical handling scheme in a wholesale operation might involve wrapping the flats in clean single-use plastic, loading them into a refrigerated truck, driving them to a distribution center, unloading them into the warehouse, loading them into a truck, transporting them to a retail store, unloading them onto the dock, moving them to cold storage, handling them in a workroom, and finally setting up the display. At any point along this route, bumpy conditions (bumpy roads) or mishandling (poor temperature management, rough handling, etc.) can result in unmarketable fruit. Minimizing the number of handling steps from field to display reduces opportunities for damage. Fruit should remain cold and wrapped during each phase of transportation. Never allow the berries to sit on unrefrigerated loading docks.

When loading a truck, stack flats on a pallet and away from the truck walls (figure 12-3). Ensure that cold air is free to circulate around the sides of the pallet and across the top and bottom. When flats of fruit are allowed to touch the floor or side walls, temperatures in the flats can rise as much as 20˚F. Do not stack flats directly over the rear wheels and use strapping or single-use stretch film around each pallet to stabilize the load. Transit vibrations can be reduced by using trucks equipped with air-suspension systems rather than spring systems.

Truck mechanical refrigeration equipment is designed to maintain temperature but currently lacks the air flow and refrigeration capacity for rapid cooling. Temperature regulating equipment in trucks does not have the accuracy to achieve temperatures below 40˚F without danger of freezing. Furthermore, high-density loads are used to minimize transportation costs, even though they inhibit cooling during transit. Therefore, thorough product cooling before loading is very important.

Fruit transportation may be beyond the control of the grower if they are selling to a wholesale distributer. To develop new and distant markets, receivers must be educated in proper handling procedures, and personal contact with the receiver before the first delivery is helpful in this regard. In other cases, handling instructions may be attached to the flats. To track conditions, small, inexpensive temperature data loggers can be placed into strawberry containers upon leaving the farm and retrieved upon arrival at the point of purchase. Examining the temperature fluctuations during transit can identify weak control points in the cold chain.

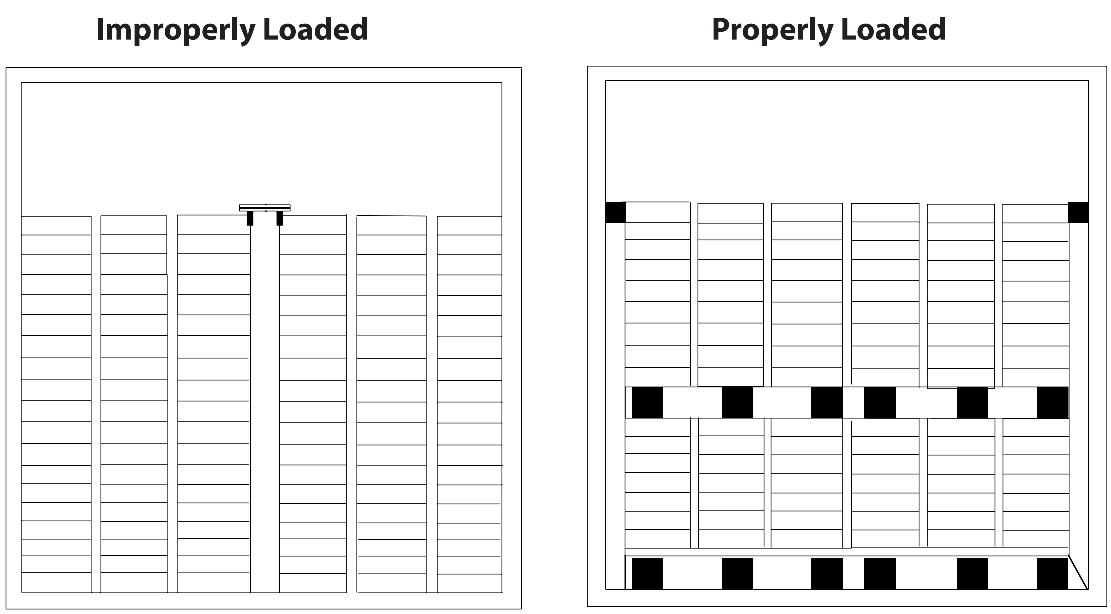


Figure12-3. Improper (left) and proper (right) loading of flats within a truck. Where improperly loaded flats are in contact with the floor and walls, properly loaded flats are removed from floor and walls and cold air is free to circulate.

Summary

By selecting appropriate varieties and using proper harvesting methods and storage techniques, it is possible to maintain quality strawberries for at least 7 days after harvest. Harvest workers should be trained to handle berries carefully to avoid bruising and contact with spoiled fruit to maximize storage life. Additionally, because most strawberries grown in the Northeast are consumed raw by consumers, worker training and postharvest sanitation are essential to reduce food safety risk. Quickly removing field heat from fruit improves storage life and can be achieved more efficiently using forced air cooling. Lastly, careful loading technique and refrigerated, clean trucks ensure that high quality, safe fruit is delivered to market.

Further Reading

Callahan, C. and A. Chamberlin. Forced air cooler: Countertop model. Build Plans. University of Vermont Extension. October 5, 2018.

Callahan, C. and A. Chamberlin. Forced air cooler: Pallet model. Build plans. University of Vermont Extension. October 5, 2018.

Callahan, C. and A. Chamberlin. Forced air cooling: Field trials. Fact Sheet. University of Vermont Extension. June 18, 2019.

Callahan, C. and A. Chamberlin. Forced air cooling on the farm. Fact Sheet. University of Vermont Extension. October 5, 2018.

Carroll, J., Pritts, M.P., 2022. Production Guide for Organic Strawberries. New York State Integrated Pest Management Program. Ithaca, NY.

Mitcham, E. 2016. Strawberry. In: Gross, K.C., C.Y. Wang and M. Saltveit. The commercial storage of fruits, vegetables, and florist and nursery stocks. Agriculture Handbook 66, U.S. Department of Agriculture, Agricultural Research Service, Washington, D.C.

Shin, Y., J.F. Nock, R.H. Liu and C.B. Watkins. 2008. Cooling strawberries – Going halfway may be enough. New York Fruit Quarterly 16(2):9-13.

Watkins, C.B. and J.F. Nock. 2012. Production Guide for Storage of Organic Fruits and Vegetables. New York State Integrated Pest Management Program. Ithaca, NY.

Citations

[1]Vance, A.J., P. Jones and B. Strik. 2017. Foliar calcium applications do not improve quality or shelf life of strawberry, raspberry, blackberry, or blueberry fruit. HortScience 52:382-387.

[2]Ferreira, M.D., J.K. Brecht, S.A. Sargent, and J.J. Aracena. 1994. Physiological responses of strawberry to film wrapping and precooling methods. Proceedings of the Florida State Horticultural Society 107: 265-269.

CHAPTER 13

Sales and Marketing

Business scholar Michael Porter discusses two basic paths to business success: (i) being a low cost, high volume provider of commodities, and (ii) creating a superior, differentiated product or service that sells at a price premium.[1] A farmer focused on maintaining low production costs must efficiently grow large and reliable quantities of berries at a relatively low cost. In turn, they spend less time and effort on marketing and strive to sell large quantities in wholesale markets, either using distributors or brokers or selling direct to grocers and institutions. In contrast, the farmer with a differentiation focus emphasizes marketing and branding. While price, efficiency and reliability are still important, this farmer needs consistent offerings of attractive and fresh berries that appear high quality, create an experience, and cultivate consumers. They must devote attention to telling the story of the products and/or experience they offer. These farmers will likely sell direct to consumer using farmers markets, CSA, farm stands, or pick-your-own (PYO).

Of course, these focus areas are end points of a continuum with much gray area in between. Farmers can be successful at many points along this continuum and the right niche for a given operation depends a great deal on the answers to the following questions: "What kind of operation do I want to be? How do I want to spend my time? What activities do I enjoy most? What activities do I do best? Which will make the best use of my own scarce time?"

Selling Approaches

Strawberry farming has a long history of direct market sales, but strong consumer demand for regionally produced fruit suggests there is also potential for specialized wholesale production. Both channels have advantages and disadvantages. Selling direct to consumers requires a customer base to support recurring sales and has many considerations, but should also yield a high return per acre. Wholesale requires established relationships with buyers who may demand certifications and traceability, but also might offer a guaranteed price and a stable outlet. It is common for growers to sell through a variety of markets to reduce waste and maximize revenue.

Direct Market Sales

There are many considerations farmers must take into account when selling direct to consumers, as customer impressions of the atmosphere, actions and presentation of staff, customer service, aesthetics, and quality of products and environment, impact their level of satisfaction. The farm, retail space, and surrounding areas should be kept tidy and organized, as this conveys a professional and well-run organization. The following areas of consideration are applicable to all retail outlets (such as farm stands, markets, and CSAs) and PYO operations:

- *Fruit quality*. Fruit quality can set farms apart from grocery stores and is an important part of establishing clientele. Fruit should be picked daily (or noted otherwise and graded heavily), undamaged and free of pests, and presented neatly in containers. Postharvest handling of the fruit is critical when dealing with the fresh market and may require a considerable investment in packing, storage, and transportation facilities (Chapter 12).

- *Customer service*. Staff should be well-trained, knowledgeable about the business and its processes, and most of all, friendly and professional. There is no easier way to ruin a customer's experience than a negative or unprofessional interaction with staff members. Staff should be trained to handle a variety of situations that may arise and know whom to contact in the case of uncertainty.

Photo 13-1. Handwashing stations and PYO policies at the entrance to a PYO operation (E. Hodgdon).

• *Bathrooms.* Clean and accessible bathrooms with handwashing stations are essential.

• *Directions, parking & accessibility*. Be prepared to provide directions to the business online and over the phone. Parking areas should be clearly marked, well-designed, and safe. Design traffic flow so that customers do not need to drive in reverse, especially in front of play or petting areas, as this could put children at risk. Accessible parking should be available, clearly marked, and reserved only for those who need it.

• *Payment*. Accept as wide of a range of payment methods as possible. Consumers vary in their payment preferences, often along generational lines. Mobile payment has become standard, especially among younger generations. There are many mobile payment methods, including mobile wallets, contactless payments, credit card payments, and direct transfers of money through apps. Checks are not widely used and can be problematic, but it is prudent to accept this form of payment from local customers, especially those not comfortable using credit cards or technology. Ensure that all payment methods are integrated into daily accounting activities, and that applicable taxes are deducted.

Pick-Your-Own (PYO) Strawberries

At a PYO operation, customers visit the strawberry field to pick fruit themselves. PYO has proven successful for many growers, either as a seasonal offering and extension to a retail outlet, or as a stand-alone business. Some CSA-only farms offer PYO as part of a CSA share, which can add to the experience of being a CSA shareholder.

In one study, 15–30% of people said they had picked strawberry fruit within the last year.[2] Another survey reported 17%. Thus, while strawberry seems to be well-known as a PYO crop, there are significant opportunities for increasing the number of PYO customers. New PYO customers will likely be inexperienced and require training and rudimentary education before they feel comfortable picking fruit. This training can be communicated in several ways (signs, verbally, etc.) and also creates an opportunity to connect with customers, teach them about food production and farming, and help support a positive interaction with agriculture.

At face value, PYO appears to reduce labor, storage, and handling costs, but this model comes with many other costs and considerations, and the success of a PYO operation can depend on location. It takes 1,250 PYO customers to harvest 1 acre of a productive strawberry planting (assuming 15,000 lbs fruit and sales of 12 lbs/customer). Furthermore, PYO fields need to be staffed, often by more than one person, to manage sales, parking, crowds, and answer questions. The business should also provide bathrooms and must have adequate insurance coverage. Customers tend to eat fruit in the field while picking, which has led a number of farms to implement strong policies against fruit consumption. Fruit consumption might seem like a minor irritation, but if each customer eats just 5 strawberry fruit, the business will lose revenue on 275 lbs of fruit to customer consumption. Therefore, PYO operations should consider revenue losses to consumption when setting prices.

To prevent against loss and reduce rotten fruit in the field that can foster diseases and pests, strawberry plants must be cleanly harvested every 2–3 days. PYO customers will not harvest cleanly and methodically, but rather customers will pick and choose fruit. It is possible to use a flagging system to indicate where customers are permitted to pick to concentrate picking, but it is still unlikely that plants will be picked clean. Therefore, many PYO areas are picked thoroughly by a trained crew periodically.

Important PYO considerations

• *Location.* A PYO location should be easy to find. PYO fields on or near major roadways are easily accessible, but many successful PYO farms are in less-than-ideal locations. Parking should be clearly marked and organized, and roads should be accessible to all vehicle types; otherwise, transportation should be provided. Signs should be in place to direct customers on where to park.

• *Signs*. A sign with the farm's name should be prominently displayed. Signs should be visible, neat, high-quality, attractive, and easy to read. Select colors with care, as there should be enough contrast between the background and lettering to make the sign easy to read. At 50 mph, a motorist has only 3-5 seconds to read a sign. Make sure lettering is large enough to be read by passing motorists. Symbols are often more effective than words. Use pictures or the company logo on signs when possible. Contact the town to make sure signs are in compliance with any local guidelines.

• *Communicate PYO rules*. PYO policies and processes (photo 13-2) should be prominently posted and address hours of operation, expectations for supervising children, the price of fruit and how customers are charged, a policy on consuming fruit while picking, the treatment of plants and equipment in the field, pet policies, and safety expectations. Safety procedures should be clearly stated and reiterated to customers when they check in with staff. Children must be supervised. Depending on the location, it can be a good idea to have alternative amusement for children, such as a playground. See *How Can I Manage Food Safety Risks at My Pick-Your-Own Operation.*

• *Determine how customers will be charged*. There are several ways to charge customers for the fruit they pick. Historically, PYO operations have charged by weight after customers pick using an electronic scale. Using this approach, customers either bring their own picking containers that are weighed prior to picking or are provided a picking tray or container that they may be required to purchase at the end. If customers are expected to pay after picking, it is beneficial for the business to let them know how many pounds a container holds so that customers do not over-pick. While over-picking might seem like a nice outcome, this only holds true if they are willing to pay for the fruit they don't want, which is not always the case. Another approach to charging customers is a pre-pay system for a specified volume of fruit. A pre-pay system eliminates scales and any uncertainty about cost or fruit quantity.

Photo 13-2. Communicating PYO rules (K. Orde).

• *Train staff and provide excellent customer service.* Customer service is key to the PYO experience. Staff should be friendly, helpful, and know about the business and at least something about strawberry production. Staff should assist with parking and orient customers upon arrival. Remind staff that this may be the first time customers have been to a farm or picked a crop, which can make the experience exciting and overwhelming and is likely to affect customer behavior. Staff should clearly explain how the PYO process works so that customers are comfortable. They should also ensure the check-out area is clean, organized, and efficient.

• *Consider customer comfort.* Customer comfort has been identified as a key aspect of successful PYO operations. A positive experience is likely to boost sales, as customers who are enjoying themselves may continue picking and purchase more fruit.[2,3] One survey found that despite initial impressions that plastic mulch appeared less "natural," after picking

How Can I Manage Food Safety Risks at My Pick-Your-Own Operation?

Maintaining sanitary PYO conditions is essential to minimize the risk of foodborne illness and reassure customers that the business is selling a high-quality product and safe farm experience. Consider adopting the following food safety practices at your PYO operation:

- Clearly state farm food safety policies* online and conspicuously post signage with important information at the entrance of PYO fields.
- Inform customers that they should not visit the farm if they are feeling ill.
- Maintain a "no pets allowed" policy in PYO fields. Pets can transmit human pathogens and frighten farm animals and other customers.
- Provide restroom facilities for customers* and ensure that facilities are cleaned regularly based on use. If applicable, have the porta-potty provider contact information readily available if problems arise.
- Offer handwashing stations for customers with soap and water (photo 13-2). Many plans are available for low-cost portable hand washing stations that can be built with common materials.
- Provide customers with new, clean berry containers. If customers bring their own containers, line them with food grade plastic bags. Do not redistribute single-use pint or quart containers, or cardboard flats returned to the farm by customers, since they cannot be sanitized between uses.
- If reusable berry carrier trays are provided to customers, clean and disinfect handles and surfaces between uses.
- Consider using a flagging system to manage harvest efficiency and minimize subsequent overlap of picking locations between customers. Customers can be assigned a row and given a flag to place where they stop picking. The next customer can then be assigned to resume picking where the previous person left off.
- Discourage eating, drinking, and smoking in the field. Offer designated picnic areas away from the berry field.
- Provide trash cans and signage to discourage littering.
- Develop standard operating procedures for cleaning and sanitizing scales, counters, tables, and food contact surfaces on a regular basis.

*Recommendations designated with an asterisk are required for farms subject to the Food Safety Modernization Act's Produce Safety Rule (21 CFR § 112.33).

Am I required to allow the public to bring support animals onto my PYO operation?

While service animals must be allowed in areas of the farm where the public is permitted (such as PYO fields and retail stores), comfort, companion, and emotional support animals are not currently covered by the protections of the Americans with Disabilities Act. Legally, the business may ask if a service animal is required because of a disability, and may inquire about the job that the animal is trained to perform for its handler. <u>It is *not* legal to ask the owner to disclose their disability or service animal documentation.</u> Remember, not all disabilities are visible, and not all service animals wear vests. If a service animal is behaving in an unsafe or disruptive manner, ask that the animal leave the farm. For more information, seek legal advice from a professional and consult local rules and regulations.

begins, individuals generally preferred picking on plastic-mulched raised-beds to matted row beds, likely because the higher bed height decreased how much they had to bend over.[2] As Henry A. Wallace wrote, "*The modern American back does not seem to adapt itself to strawberry picking".*

• *Managing crowd size*. To manage the number of PYO parties onsite at a given time, request that customers make reservations ahead of time over the phone, through smartphone apps, or on the farm's website. To guarantee that customers show up for their time slot, it may be a good idea to charge a non-refundable fee or have customers' pre-pay.

Pre-pick Retail Sales

As long as there is a market for and labor to pick fruit, selling strawberry fruit at retail prices is a great option for maximizing returns. Roadside stands, farm stores, farmers markets, and CSAs are all good options for retail sales. Selling through the farm's own store creates opportunities for sales of additional value-added items, including preserved and processed strawberry fruit. In a farmer's market setting, customer service and fruit quality are paramount.

Online sales for pickup and delivery are becoming increasingly popular. Farms that can rise to the occasion under stressful circumstances (such as pandemics!) are well-positioned to gain new and repeat customers. There are a number of direct sales software programs to facilitate online sales. These programs keep track of inventory and charge customers for products, taxes, and any applicable shipping/handling fees. The same can be done through the farm's website, assuming it uses a platform that can host this transaction. For all online sales, customers should be able to select a pickup time or home delivery and be given clear instructions on how the transfer of goods will occur. Shipping of strawberries is not widely practiced, but some companies do successfully ship fruit. It is also possible to ship canned products.

An online sales interface must be integrated into the business's existing online presence, professional and trustworthy in appearance, and thoroughly tested prior to deployment. Be sure to monitor online sales to ensure orders are fulfilled on time and to make any adjustments to inventory.

Wholesale Fruit Sales

Wholesaling involves harvesting large volumes of fruit, cooling fruit to prolong shelf life (Chapter 12), and delivering fruit directly to a customer supermarket, distributor, food hub, institution (school, college, hospital), or produce auction. Wholesaling fruit is an option for growers without a strong customer base for retail sales and/or for those who wish to specialize in strawberry production and move quantity. Combining retail and wholesale sales can be beneficial on many farms, as long as one of the markets is not getting the low-quality leftovers of the other. If one buyer is receiving lower-quality fruit, then that should be clearly understood by the buyer, and they should be charged accordingly.

Some established commercial growers have business partners who are willing to purchase excess fruit at a wholesale price without a formal agreement. However, beginning farmers or those breaking into wholesale sales must first develop relationships with buyers and come to an agreement prior to the start of the season to ensure both an outlet and a fair price for the crop. Price, delivery interval, container preferences, and payment policies all need to be agreed upon in advance. Many outlets also require specific certifications and records showing food safety practices and compliance, as well as traceability capabilities.

A **produce auction** is an aggregation and marketing service that allows smaller farms to participate in the wholesale fruit and vegetable market. It allows the farmer to concentrate on growing a good product without spending as much time on marketing and services. Through these auctions, many farmers can sell produce at fair market prices without directly competing with neighboring producers. Produce auctions can be found in New York, Pennsylvania, Ohio, Ontario, and other locations. Other wholesale opportunities can be found through various food hubs and grower cooperatives.

Pricing

Fair pricing requires a thorough investigation of production costs (Chapter 14). There are numerous production costs that can be easily overlooked, including owners' labor, overhead costs, and the operating and ownership costs of machinery. Prices should be set to cover all production costs and result in a profit. If a "fair" price, as determined by cost analyses, is greater than the prevailing market rate, it may not be profitable to grow the crop.

Other factors that affect pricing are demand, supply, and demographic factors. Market forces have less of an impact on the price of direct-marketed strawberries than they do on the price of many other commodities, but there is generally a prevailing rate for the fruit in a given region. It is a good idea to talk with other growers or do market research in the immediate area. Generally speaking, price reductions are only a good idea when costs decrease substantially and remain low over time. Reducing prices to undercut local competition will cause more harm than good, as lower prices yield lower profits and growers will need to increase sales to make up for lost revenue. Cutting prices may also prompt competitors to lower their prices in response, creating a price war that is likely to result in all participants selling their crop below the break-even price. In addition to the harm this causes to involved businesses, undercutting devalues the crop and gives consumers the impression that other growers are overcharging.

For farms that sell to local wholesale markets and at their own retail market, the issue of customer perception is particularly relevant. Regional grocery chains have been known to sell produce for less than the market rate as a loss-leader to attract customers. Wholesalers would be wise to engage with buyers (especially grocery stores) about the importance of not devaluing the crop. This will help maintain the value of the product for other outlets, including the grower's own retail stand, as well as for other regional producers.

Season Extension

Season extension strategies (such as high or low tunnels) can allow for strawberry fruit production outside of the traditional season. Being the first or last business with fruit may permit a premium price, and the availability of local fruit outside the traditional season may attract customers who will hopefully purchase other items. This is a variation on the loss-leader strategy, where the business offers attractive items to bring customers to the point of purchase (see Chapter 4).

Customer Expectations and Service

Regardless of whether a business sells wholesale, retail, or via PYO, it provides many services that extend beyond direct "customer service." It is helpful to think of service as a spectrum with highly tangible goods on one end, and less tangible goods on the other—where a quart of fruit is highly tangible, the experience of walking around farm property or interacting with staff at a farmer's market is entirely intangible, and the PYO experience lies somewhere in between. Both tangible and intangible experiences impact customer satisfaction. A farm can have the highest quality product, but if being on-site is unpleasant or lacking in some way, sales may be negatively affected, customers may be less likely to return, and poor reviews of the business can occur.

You're in the "service" business

Many farms provide far more services than they are aware. Identifying the services that the business offers (or that could be offered) allows the business to meet, and even exceed, customer expectations. To identify services and service opportunities, think of all the ways customers interact with the business from the moment they pull into the driveway until they leave.

A critical step to providing quality service is knowing what customers expect and desire. It can be uncomfortable to ask customers about their expectations and experiences, and sometimes feedback can feel personal. However, research shows that most customer expectations are not excessive. Competence, flexibility, fairness, an ability to provide explanations and accommodations, respect and empathy towards the customer, cleanliness of facilities and employees, consistency, and a hassle-free experience, are all frequently cited as the most important factors of customer satisfaction.[4] Managers may be unaware of where they are falling short, despite best efforts. Thus, existing customers are an excellent resource for gaining insight into the customer experience, expectations, and desires. While acquiring new customers may also be important, businesses tend to overemphasize acquiring new customers instead of nurturing relationships with existing ones.

There are a variety of low-cost tools that can be employed to do gain insight, including surveys, meetings and interviews, customer panels, market research on customers and competitors, and investigations into complaints and lost customers. These tools help identify areas of improvement, and also support the development of best practices. Before conducting surveys, set a clear and specific question to guide research, such as "what products and services do our PYO customers expect when they visit the farm?". Keep the survey simple to ensure that responses can be used in later decision making. It is easy to continue adding questions to a customer survey, but this will make dealing with the data more time-consuming and may even deter customers from participating. Once the business has identified what customers want, it needs to determine how to provide it. The solution need not be costly; often a few small, affordable steps can improve the customer experience greatly.

Consumer Prefrences

When it comes to marketing strawberry fruit specifically, consumer preference studies have found that gender, age, ethnicity, race, and geographic location influence preference greatly. One study seeking input on the "perfect strawberry" found that female respondents were not enthusiastic about purchasing fresh strawberry fruit from "big box stores," and male respondents were most interested in strawberries grown in home gardens.[5] The same research reported that customers aged 22–30 had a strong interest in fruit from local farmers markets or home gardens, whereas the top drivers for other age groups were flavor and sweetness (ages 31–40), a fresh fruit topping for ice cream (ages 41–50), fresh sliced berries (ages 51–60), and a berry that melts in the mouth (ages 61–70). The same survey reported that the nutrient content of fruit was not a major factor in the decision to purchase strawberry fruit, indicating that using words such as "flavorful" and "high-sugar" might generate more sales than an approach that emphasized health benefits.

Setting & Upholding Expectations

A customer's experience is informed by their own personal needs, philosophy, and expectations, and each person will have varying tolerance for less-than-ideal service. However, it's still worthwhile to take steps to set and meet expectations:

- *Ensure that the business is fulfilling explicit promises*. For example, is the PYO field or retail store open as early or late as promised? Can customers shop comfortably until closing time without feeling rushed? Marketing communications, website/social media content, and information communicated by staff should be consistent and upheld during normal operations.

- *Be aware of the implicit promises being made*. Branding efforts, social media messaging, the shopping environment, the pricing strategy, etc., all send a message about what customers can and should expect. High prices tend to convey quality; thus, strawberry fruit should appear and taste excellent and the shopping and customer service experience should be positive as well.

- *Manage word of mouth*. In addition to conversations between people who know each other, word of mouth now includes social media and online reviews. Many customers have the perception that these word of mouth sources are unbiased, even if they aren't. Because of this, online platforms pose opportunities and challenges for businesses (*See Negative Online Reviews & Product/Service Failures*).

- *Be conscious of customers' past experiences*. These may include previous experiences at the business or at similar types of businesses or competitors. These past experiences will both set expectations and create opportunities.

Advertising, Public Relations and Branding

Advertising and public relations fall under the umbrella of marketing, as they help to promote and sell products and services.

Advertising refers to announcements by the company that are intended to draw attention and increase interest in products or services, build a customer base, develop customer loyalty, and boost sales. Advertising is part of some, but not all, marketing plans. Advertising can take many forms, including print, social media, signs, mobile and internet advertisements, audio, video, and billboards. The key to advertising is to create awareness, spark interest, build a desire in customers, and drive them to take action (and make a purchase).

Public relations is usually focused on the reputation of the business and its relationship with external and internal customers (including employees). Generally, good public relations supports a positive reputation by building relationships with customers, suppliers, stakeholders in the community, organizations, and even reporters. Media outlets love small businesses and are often willing to run a feature story about a farm. Try to get to know local reporters and don't hesitate to reach out to them about farm activities or offerings that the business is willing to discuss publicly. Media coverage generate awareness about the business in large audiences and helps to build the company brand.

Branding is the overall strategy of how a company presents itself and what it represents. Logos, messaging, physical spaces, and the way the business interacts with others, all contribute to (and help define) the company brand. Company culture, business priorities, and values, also contribute to brand, as internal employees perpetuate the tone set at the top or by managers. Most businesses have a brand, though some brands are stronger than others, and some brands are more intentionally formulated and developed. Consider what you want people to think and how you want people to feel when they hear the business name, and then work towards building this. It is also important to understand if the public's current understanding of the business matches what the company wants their brand to be (or thinks that it is). Marketing efforts have huge potential to affect the brand; therefore, it is incredibly important to consider how the tools listed below are managed.

Messaging

All marketing communications should be consistent and align with the company mission, goals, and brand. Mixed-messages are confusing for the public, and actual or perceived discrepancies between what is promised and what the customer experiences can lead to disgruntled customers and poor reviews of the business.

Harmony in messaging requires significant effort, and internal communication must be good and coordinated across teams. This means getting everyone on the same page—from the field, to the retail stand or farmers market, to the social media managers. Staff should know what's coming and when so they can plan marketing activities accordingly. Keep in mind that repetition is important in marketing and that the business will tire of its messaging long before any customers will.

Channels

The following channels are important components to many marketing plans. To make the most of these tools, they should be used consistently and actively. They should also be managed by a person who has a clear understanding of the company's brand and messaging approach.

Websites

A website is key to communicating logistical information (hours, location, etc.) as well as information about the business and why customers should visit. Websites should be thoughtfully designed and consistent with all other marketing communications. A website should include hours of operation, address(es), phone number(s), an email address or contact form (that someone checks regularly), information about the farm, and important policies. Websites may have an online store to sell goods for shipment, pick-up, or delivery, and be used to make reservations for PYO and other agritourism activities. There are a number of intuitive website building companies that make it possible for someone without graphic design experience to put together and launch an attractive and functional site.

Crowd-sourced Reviews & Word-of-mouth

There are many online platforms that gather and publish customer reviews, and these are widely used by the public. Favorable reviews reflect positively on the business and will encourage new customers to visit. Some businesses encourage online reviews by texting or emailing customers a link after they visit and/or by offering discounts to reviewers. Customer review websites usually give businesses the opportunity to "claim" and populate the page about their business with accurate information and favorable pictures. It is also important to manage negative reviews (see *Negative Online Reviews & Product/Service Failures*).

In addition to managing search engines and review sites, farms should contact the State Department of Agriculture to place the farm's name and address on lists of agricultural producers. Some state Extension services also compile comprehensive farm lists and maps for the public.

Social Media

Maintaining a social media presence is an important part of marketing communications and can also offer affordable advertising opportunities. Current social media platforms will surely be replaced in the coming years, and it is important to keep up with the newest communication tools.

The key to social media is knowing how each platform can be used to benefit the business. Social media is a powerful tool for branding and positioning, and businesses should make sure their social media accounts are in line with their marketing strategy, brand, and values. It is also possible to use customer posts for promotional purposes, but this should only be done if these posts align with the image and brand the business wants to put forth.

When building a social media page or a post, it is absolutely essential to comply with the conventions of each social media platforms (e.g., knowing the "dos" and "don'ts"). An amateur social media presence can convey a poorly managed business (a perfect example of an undesired implicit promise). Thus, it is prudent to have a person running social media who understands both the platform and the brand. Keep the following considerations in mind:

- *Use a business account.* The business social media account should be distinct from personal accounts. Sharing personal information is a matter of preference but can be interpreted as unprofessional.

- *Consider multiple social media platforms.* Using multiple social media platforms is time consuming but there are tools that allow users to create a single post and broadcast it to all linked social media platforms. This is helpful for reaching different customer bases and ensuring consistency.

- *Managing social media takes a lot of time!* Planning and developing quality content is very time consuming, and a passive or quick attempt at social media is rarely impressive or effective in promoting the business.

- *Have a consistent message and brand awareness.* Social media should be managed by just 1 or 2 people. Each person has their own style, and if too many people are involved the messaging and appearance is likely to be inconsistent and may not be in line with the company brand.

- *Take enticing and quality photos.* The angle, subject matter, and lighting all impact how a photograph will be interpreted and the "vibe" that it gives customers. The content that is shared and the way it is shared should be decided ahead of time as part of the larger branding effort for the business.

- *Use hashtags.* A hashtag (#) is an identifier to allow other users to find post with similar content. Adding a hashtag allows for people to find the business through social media. Some examples: #strawberries, #pickyourown, etc. For a hashtag to work, do not put spaces between words or use punctuation.

- *Determine how frequently the business will post.* The business should make efforts to keep the customer base engaged without overwhelming them. Different platforms have different norms about how frequently to post. Again, having someone running social media who knows these conventions will help the business's public image.

• *Consider advertising*. Social media allows a business to advertise (boost) a post. Advertising can target people from a certain location or with particular interests.

• *The timing of posts matters.* It is good to post or schedule a post for first thing in the morning or evening. People tend to look at their social media accounts when they wake up and go to bed. That said, don't wait to post important information. If you're the first on the block to open PYO, spread the word!

• *Check for spelling and grammatical errors.*

Speaking with the Press

In many instances, the skills that are required to run a successful business are not always the same as those required for dealing with the media, and for many reasons, it can be difficult to effectively convey a story during an interview. This is compounded by the fact that reporters do not work for the interviewee and may ask provocative questions with the hopes of eliciting interesting responses. That said, do not be wary of reporters – just consider when and how you want to engage with them, and prepare yourself beforehand by anticipating the questions that are most likely to be asked. A good rule of thumb is to put your best foot forward and speak candidly but remain positive!

- Have a positive attitude. Do not be arrogant or defensive.
- Be honest and make factual statements but do not overshare or overpromise. Avoid bringing up a topicwhen there is not ample time to clarify it.
- Come with a couple key messages in mind and tell a story. Sharing emotions can draw viewers in and improve believability. Similarly, if there is a new product or service, or if the business is solving a problem, communicate what this means for customers.
- Avoid using too much jargon and give responses that someone with little agricultural background can mostly understand. Demonstrate respect your own domain knowledge, however.
- Consider using metaphors. Metaphors can communicate information in a way that is identifiable to different audiences.
- Be true to yourself and your company's brand. It is okay to share the realities of farming but keep in mind that you do not want to deter customers from visiting your farm by painting a negative picture. You may also want to be conscious of being inflammatory or placing blame.
- If you receive a question that is difficult to answer because it lacks understanding, don't get flustered. In this case, try clarifying and/or redirecting the question.
- Do not feel compelled to respond to provocative questions. It's okay not to take the bait!
- Avoid statements that could be misinterpreted, taken out of context or inflammatory.
- Don't make any statements you don't want to read in tomorrow's paper or see yourself saying on video for years to come.
- Think ahead of time about how you want to answer questions on "hot topics".

Email Comunications
Email allows for direct communication with customers. Promotional emails need to be professional; it can be helpful to use an email marketing service to help with design and to track engagement.

- *Use a business email address.* Consider setting up an email address with the same URL as the website. For example, for Alan's Berry Farm, a professional address would be contact@alansberryfarm.com
- *Don't send emails too frequently.*
- *Only send emails with important content.* Emails should be short and to the point. The subject line should make the customer want to open the message.
- *Allow customers to subscribe or unsubscribe to newsletters.* To build a mailing list, collect contact information from customers whenever possible, such as during checkout, online, and through surveys and feedback requests.
- *Proofread.* Review a test email before sending the email to a group list.
- *Do not "cc" (carbon copy) other customers.* Doing so will allow all customers to see each other's email addresses. Instead, if not using an email marketing service, use the "bcc" line to send to multiple recipients.

Magazines and Newspapers
Regional magazines and local newspapers frequently profile local farms, which can be a great promotional opportunity for reaching a regional customer base. Consider asking to review the article for accuracy before publication. Local trade publications or farm bureau publications offer opportunities to advertise alongside other area businesses.

Television and Radio
Local media can provide valuable promotion at no charge by running a feature story about a farm. While it might seem difficult to obtain such coverage, radio and TV stations often welcome opportunities to talk with growers and highlight a seasonal activity or crop. Do not hesitate to reach out to media outlets and invite them to visit the business if this type of coverage is desired.

If interested in advertising over radio, be sure to target stations and programming that you want the business to be affiliated with. Repetition is the key to radio advertising, and it is better to buy 20 spots on one station than one spot on 20 stations. Sponsoring segments may be an alternative option. Television advertising is typically quite expensive. In addition to airtime costs, production expenses to put together a quality ad can be very high.

Negative Online Reviews & Product/Service Failures

Even the best companies have service failures. It can be upsetting to read customer complaints, especially for small business owners who are working their hardest. This is one reason why it can be beneficial for a non-owner to manage customer complaints, online reviews, and social media.

Complaints and negative reviews may or may not follow an actual failure, but they should all be taken seriously. Believe it or not, only 50% of customers with a complaint ever make it known to the business, so while it may not feel like it, the customer who does complain provides an opportunity to fix an issue and to fix the relationship with the customer. Complaints that the business should be most worried about are those that are never made, but instead are spread by word-of-mouth and online or over social media platforms. If a customer has a complaint, it is better for the business to hear from them directly, and some businesses explicitly welcome feedback for this reason. When encountering a complaint, take the following steps:

1. *Document it.* Establish a consistent procedure for recording complaints and unsolicited feedback.

2. Recognize that the business is now in what is called the "service recovery phase" and the business must move quickly. Research shows that if the situation is addressed and rectified within 24 hours, about a third of customers who complained become satisfied with the company.[6] Some customers are even more likely to return to a business after they have complained if it was handled well! If the complaint is not handled well, then customer leaves the situation with 2 negative experiences.

3. *Respond appropriately.* Customers want the business to understand their perspective, take accountability, be honest and provide explanations, and treat them fairly. Some research shows that empathy can diffuse the situation more effectively than explanations, but if the customer is extremely upset empathy may further aggravate them.[7] In certain cases, a thoughtful and factual explanation can be very effective.[7] Research shows that when complaints are made online, moving the conversation with the customer into a private chat and apologizing decreases the chances of a complaint or post going viral, but only if communication occurs right away.[7] Businesses should be weary of offering compensation in a public space or right away, as others will come to believe that if they complain, they too will be offered some sort of compensation. The practice of offering compensation has also shown mixed results.

Sometimes conflict arises during the complaint process. While customers can be difficult and angry, try to use the situation to cultivate a relationship and be sensitive to feelings they may be experiencing.

Value Added Products

Consider providing recipes for customers to help them envision meals and desserts that incorporate strawberry fruit and other products on the farm. Doing so may help to promote sales.

There are also a number of ways excess fruit can be turned into value added products. This is by no means an exhaustive list. Businesses need to make sure they have proper state certifications to process fruit. Check with the state's processing authority to determine what products can be produced on the farm.

Frozen

Selling frozen berries is a good way to take excess fruit that might otherwise be wasted during peak season and turn it into revenue. Offering frozen local fruit during the off season may lead some customers to purchase local berries at the retail store instead of buying fresh or frozen fruit at the supermarket. Few families have sufficiently large freezers or take the time to store all of the fruit they will consume during the off-season, so selling frozen berries can extend the season and add value to the product.

Freeze shortly after harvest to avoid losing flavor and to preserve color. When berries freeze, ice crystals can form inside the cells, rupturing the cell membranes. The resulting thawed fruit is usually softer and more flaccid. There are methods to reduce crystallization, such as adding sugar prior to freezing, which draws water out of cells so that less is present to crystallize. Furthermore, rapid freezing results in smaller ice crystals than slow freezing. Instantly quick frozen (IQF) berries maintain their integrity after thawing. Many processing plants have IQF technology. Frozen fruit can be packaged in a container or bags. A freezer on site, ideally with glass doors, is best for displaying frozen local fruit.

Individual states have regulations regarding fruit processing. In some states, freezing is not considered processing, so it is not subject to certain health department guidelines. Check with state authorities about regulations before attempting to freeze berries for later sale.

Processed

Growing strawberry fruit for processing requires many of the same efforts as selling fresh fruit, such as contacting buyers, filling orders, and delivering. Growers who process products themselves must follow appropriate state and federal sanitation and labeling regulations. This may include undergoing regular inspections, purchasing stainless steel equipment, and using water treatment. Contact the state department of agriculture and/or health department for details. The business may be eligible for a Home Processing Exemption.

Jams, Jellies and Preserves

Value added products, such as jams and jellies, may generate a higher profit margin than fresh fruit but also requires far more inputs. Labor costs will be higher, and appropriate cooking tools will be needed as well as a steady supply of ingredients, jars, labels, and shipping boxes. The business may be eligible for a Home Processing Exemption which varies by state.

Jams (made with fruits and seeds) preserves (made with pieces of large fruit), and jellies (made with filtered juice) comprise 4 ingredients: sugar, fruit, pectin, and acid. Recipes are easy to find but need to stay within certain ranges of fruit (30-35%), sugar (65–70%), and acid (pH= 2.9–3.3) to legally label a product as a jam or jelly.

Wine

Fruit wines are a niche product, but local wines are gaining in popularity, especially if the farm has a tasting room onsite. The value of wine from a pound of strawberries can be ten times greater than the value of the fresh fruit.

Strawberry wine can have excellent color, balance, and flavor properties; however, it can be very unstable and should be consumed soon after bottling or kept refrigerated. Novice vintners may want to attend a seminar on wine making for more details on wine production.

Businesses need a license to sell wine. Wine sales are regulated by the state and there are specific staffing guidelines as well. Check carefully with your state government about rules surrounding the production and sale of strawberry wine.

Further Reading

H-2A Visa Program. U.S. Department of Agriculture.

"No Pets Allowed" and Other Rules for a Berry Safe Pick-Your-Own Experience. Connie Landis Fisk. March 1, 2019.

Hultberg, A. and E. Tepe. 2020. *Build a Low-Cost Handwashing Station on the Farm.* University of Minnesota Extension.

Improving Hand Washing Stations. The University of Vermont Extension: Ag Engineering.

Frequently Asked Questions about Service Animals and the American Disabilities Act. U.S. Department of Justice.

Kline, W. and M. Melandez. 2019. Are You Required to Let the Public Bring Their Animals onto Your Retail Farm? Rutgers Cooperative Extension.

Orde, K., B. Sideman, M. Pritts, and K. Demchak. 2018. Low Tunnel Strawberry Production Guide. University of New Hampshire Cooperative Extension Publication.

Cornell AgriTech: Food Venture Center (food processing and safety, beverage production, etc.)

Food Preservation Resources. University of New Hampshire Extension.

Food Preservation Resources. Pennsylvania State University.

Citations

[1]Porter, Michael E. 1980. Competitive strategy: techniques for analyzing industries and competitors. New York: Free Press.

[2]Stevens, M.D., J.D. Lea-Cox, B.L. Black, and J.A. Abbott. 2007. A comparison of fruit quality and consumer preferences among three cold-climate strawberry production systems. HortTechnology. 14(4):586-591.

[3]Safley, C.D., E.B. Poling, M.K. Wohlgenant, O. Sydorovych, R.F. Williams. 2004. Producing and marketing strawberries for direct market operations. HortTechnology 14(1):124-135.

[4]Parasuraman, A., L.L. Berry, and V.A. Zeithaml. 1991. Understanding customers' expectations of service. Sloan Management Review 32:39-48. (Referenced though Zeithaml et al. [2018].

[5]Colquhoun, T.A., L.A. Levinm H.R. Moskowitz, V.M. Whitaker, D.G. Clark, K.M. Folta. 2011. Framing the perfect strawberry: An exercise in consumer-assisted selection of fruit crops. Journal of Berry Research. 2(212):45-61.

[6]2015 Customer Rage Study conducted by Customer Care Measurements and Consulting and the Center for Services Leadership at Arizona State University. (Obtained though Zeithaml et al. [2018] publication referenced above)

[7]Harvard Business Review. 2020. How to keep complaints from spreading. (May-June):19-22.

CHAPTER 14

Budgeting & Costs

This chapter explores the financial side of strawberry cultivation using methods common to cold temperate regions of the United States. Budgeting requires understanding the costs associated with production, projecting anticipated revenue, and comparing the two to estimate the profitability of a strawberry enterprise.

Budgeting is a necessary activity for any business for several reasons. First, understanding production costs can help producers set pricing that at least meets input costs (the break-even price) and hopefully is profitable. Second, knowing the costs associated with production and selling a crop can provide insights into where modifications can be made to make the crop more profitable for the business. Comparing production costs with industry benchmark figures can identify inefficiencies in the operation. Third, assessing the profit margin for each product or activity can help businesses prioritize those that earn a profit.

This chapter aims to assist strawberry growers with the budgeting process by providing a thorough list of activities and materials that carry costs for strawberry producers. We provide both a downloadable workbook and printable worksheets for tracking expenses and projecting revenue. Since there is no "standard" production system in northeastern North America, we list a diversity of systems, materials, and activities—not all of which will apply to every farm. The supplied tools are easily customizable.

Basic Vocabulary

Enterprise budgets are used to understand the costs and revenues associated with specific crops or activity.

There are two main categories of expenses for businesses: overhead and operating. **Overhead** costs are those associated with running the business, and generally don't change. These include insurance payments, management salaries, electricity, internet, and other services. Overhead costs are not the focus of this resource but are very important to understand because they must be distributed across goods and services sold (we do include a section in the budgeting resources for allocating overhead costs to the strawberry crop to estimate total costs of production).

Operating costs are those associated with producing a product or providing a service. They can be **fixed** (do not change regardless of what is grown, how it's grown, etc.), such as land rent or equipment payments, or **variable** (vary depending on what or how something is grown), such as labor, seed/chem/other inputs, and diesel. There can also be **semi-fixed** costs, such as marketing or equipment maintenance.

Some businesses put all labor costs into overhead, especially when workers will be paid the same wages regardless of business activities. However, it can still be helpful to include labor in an enterprise budget to understand the total operating costs of crop production, especially when labor can be such a large portion (as with strawberry).

Using the enterprise budget, it is possible to understand **total costs** of production (both operating and overhead in this case), **revenue** (income generated from the crop), **profit** (income minus total costs), and the **break-even price** (the price at which the profit is $0).

Budgeting Resources

This guide includes two user-friendly budgeting resources. These resources can be used for planning purposes, to examine a typical planting, and/or to budget out a new planting through its lifecycle—from the preplant period to the final bearing year.

#1 - Downloadable Workbook

This is a Microscoft Excel Workbook (https://scholars.unh.edu/extension/1671/) that you can download and fill out on your computer. This thorough resource covers costs associated with machinery (both ownership and operating) and operating costs associated with the preplant, planting, and bearing year. It also includes a list of typical overhead costs to help calculate total overhead for the operation.

The downloadable workbook has 5 tabs that will autogenerate totals from the data that is entered, including: an income statement with a profit/loss value for each period (by "period" we mean: the preplant period, the planting year, and bearing years) as well as cumulative profit/loss for the planting. Since this resource is segmented by period, you can begin filling out this document at any crop stage (or retroactively).

#2 - Printable Worksheets

These Printable Worksheets (pg. 183) are embedded within this chapter and are simplified versions of the downloadable workbook. Print these worksheets and use them to keep records of completed activities, throughout the season. At the end of the year, this information can be entered into the downloadable workbook or used to manually calculate the costs of production and a profit/loss value.

Instructions for Using Budget Resources

The budgeting resources are <u>not step-by-step guides</u> for strawberry production; rather, they are intended to help growers with financial planning. Only a subset of the activities and materials listed within them may be relevant to each operation. The golden rule for using these worksheets is to <u>report expenses and revenue for the same land area in all worksheets.</u> In other words, they should be used to take a specific planting through its lifecycle.

The downloadable workbook and printable worksheets are broken into the below sections Please read and follow the instructions outlined below:

Machinery Costs (Downloadable Workbook only)

This worksheet calculates per hour ownership and operating costs for power units and implements. Subsequent spreadsheets will ask for the machine hours for each activity, and total machine costs (operating and ownership). This allows machine costs to be applied directly to the strawberry crop.

Fill out the *Machinery Costs* worksheet first (before other worksheets in the downloadable workbook). One of the first fields at the top of this worksheet is the 'Annual total cost of machinery repairs'. The value entered here should include parts, labor, and services. It should reflect repair costs for <u>all</u> machinery listed, and for <u>all</u> crops and farm activities for which you use the listed equipment, not only those associated with strawberry.

Similarly, the value entered in the 'Hours of Use' column should reflect the total machine hours for all crops on the farm, not just strawberries. If this worksheet is being used for planning purposes, these values need to be estimated.

Preplant Period, Planting Year, and Bearing Year(s)

These worksheets are used to track the operating costs of strawberry production. Start with *Preplant*, and then move onto *Planting Year* and *Bearing Year* worksheets. Record the material, labor, and machinery requirements for each task during each period. These worksheets have the following column sections:

- 'Material Costs': record the quantity and cost of materials used for each activity. An average cost (or cost range) for materials is provided, but actual costs will vary depending on supplier and specifications.
- 'Labor Costs': record the quantity of hours and per hour labor cost for each task (see Labor Cost Considerations section below).

• 'Machinery Costs': for the downloadable workbook, input the machine hours required for each task and then select the 'Power Unit' and 'Implement' from the drop-down menus. The total ownership and operating costs will automatically calculate and transfer to the *Income Statement*.

For the printable worksheet, keep track of machine hours and the equipment used for each activity. At the end of the season, this information can be entered into the downloadable workbook, or alternatively, you can manually sum ownership and operating (fuel, lube, and repair) costs and allocate a portion to the strawberry crop based on the percentage of hours used for strawberry.

Overhead Costs

This worksheet lists common overhead costs to help calculate a total overhead value for the business. It is not intended to be compehensive—just for estimation purposes.

List all overhead expenses. If you're using the downloadable workbook, do not include machine costs, as ownership and operating machinery costs have already been accounted for in the *Machinery Costs* tab.

If using the printable worksheets, you will need to include machinery costs, including both ownership (lease payments, insurance) and operating (fuel, lube, repair costs) costs for the farm (not just those associated with strawberry).

Once you have determined a total overhead value for the business, this value needs to be allocated to each enterprise in the business. There are different methods for doing this. One approach is to distribute these costs proportionally based on acreage. For instance, if the strawberry crop in question is 1 acre, and the business farms 5 acres total, 20% of annual overhead would be allocated to the strawberry crop. If the farm has more than one strawberry planting, treat each planting as its own enterprise; these resources are set up to evaluate one planting across its lifecycle.

Obviously, some crops will require a greater share of overhead costs than others. Therefore, for businesses with a diverse range of enterprises allocating overhead costs accurately can be more complicated. If this is the case, you can use a weighted approach that considers the demands of each enterprise. You can also deliberately allocate specific costs, such as special insurances or crop-specific equipment.

Income Statement

This worksheet carries over the total material, labor, machinery, and overhead costs from the previous worksheets and deducts these expenses from the revenue earned from fruit sales. The result is a profit or loss dollar value for each period (preplant, planting, and bearing) and an overall profit/loss value for the planting across its full lifecycle.

If using the downloadable workbook, all that needs to be entered on this sheet are revenues from fruit sales. All other values will autofill. There is a line for adjustments should you have another expense or credit to include.

If using the printable worksheets, you will need to manually carry over the total values from the previous worksheets. Instructions for these calculations are provided.

Calculating Common Material Costs

Linear Bed Feet per Acre

The total number of feet per acre will dictate the quantity and cost of materials needed for establishing the crop, including drip irrigation tape, plastic mulch, straw, and plants. Labor needs for planting, weeding, and runner removal will also be affected. Table 14-1 estimates linear bed feet based on various bed-center spacings.

Plants per Acre

The number of plants per acre will affect both the initial cost of plant material, and the maintenance and management of these plants. Plants per acre depends on the distance between rows, the in-row plant spacing, and the number of rows of plants down each bed (single, double, etc.). See table 4-2 (Chapter 4) for determining plants per acre.

Straw and Rowcover

Straw bales average 40 lbs each (or about 50 bales/ton) and are typically applied at a rate of approximately 6 bales/250 foot row. A 6-foot bed center spacing will require approximately 174 bales/acre, whereas an eight-foot spacing will require only 130 bales/acre.

Rowcover can be purchased in many different widths, lengths, weights, and brands. Weight and brand will largely determine price. Rowcover may be reused for multiple years, which should be considered when comparing its initial cost to straw mulch (for overwintering). We provide current price estimates for most weights used for strawberry in table 14-2; check with your supplier for up-to-date pricing.

Cover Crops

The cost of cover crops varies by seed type, seeding rate, and supplier. Table 14-3 lists current seed costs for a variety of cover crops and the per acre cost if seeded alone. See Chapter 2 for guidance on selecting a cover crop, planting dates, and other considerations.

Table 14-1. Linear bed feet per acre at different row spacings.

Bed spacing (feet, center-to-center)	Total linear bed feet/acre
3	14,520
3.5	12,446
4	10,890
4.5	9,680
5	8,712
5.5	7,920
6	7,260
6.5	6,700
7	6,220
7.5	5,808

Protected Culture Structures

Like most equipment, protective structures require a significant initial investment. The cost estimates below are for structures and coverings only and do not include preparatory site work, plumbing, electrical work, etc.

Low Tunnels

A low tunnel system costs approximately \$10,000–\$20,000 per acre (~\$1.33/ft^2 or \$2.65/linear foot of bed for a commercial system with all components). The per acre cost depends on the materials used to build the tunnels and the bed-center row spacing. There are currently only a limited number of commercial low tunnel systems available. It is possible to build a low tunnel system from scratch, but you must take many considerations into account. The low tunnel guide listed among resources at the end of this chapter offers many tips.

In general, the primary components (hoops, anchor stakes, end posts) can be reused for many years, while plastic and twine/rope/bungee cording (used to secure the plastic to the frame) will need to be replaced annually or every few years depending on the thickness of the film. There are no documented negative effects of using low tunnels over strawberry and many positive effects (see Chapter 4), but revenue advantages resulting from the addition of a low tunnel system will depend on farm-specific conditions, weather, and if tunnels are used during shoulder seasons to hasten or extend fruiting.

High Tunnels and Hoop Houses

The cost of larger protective structures varies with size, design, materials, and add-on features. Caterpillar tunnels can be constructed for under \$2/ft^2, and high tunnels for \$2–5/ft^2. For high tunnels

Table 14-2. Current (2021) rowcover cost by weight.

Rowcover weight (oz)	Price/yd^2
0.50–0.60	~\$0.14
0.75–0.80	~\$0.18
0.9–1.0	~\$0.20
1.2–1.25	~\$0.29

Table 14-3. Current (2021) seed costs for a variety of cover crops and per acre cost if seeded at standard seeding rates.

Cover crop	Standalone seeding rate (lbs/acre)[1]	Price per lb[2]	Standalone cost per acre ($)
Alfalfa	14	$2.48–$4.50	$35–$63
Buckwheat	60	$0.70–$0.76	$42–$46
Rapeseed/Mustards	2–4	$1.00–$3.16	$2–$12
Clover (white, Alsike, Ladino)	2–4	$3.20–$3.80	$6–$15
Clover (Red)	8	$1.98–$3.70	$16–$30
Clover (Sweet)	12	$1.80–$4.40	$22–$53
Fescue	20	$1.60–$3.80	$32–$76
Field Brome	20	$3.20–$4.00	$64–$80
Hairy Vetch	40	$1.90–$2.04	$76–$82
Millet (Japanese)	20	$0.75–$0.96	$15–$19
Oats	3 bu	$9.25–$11.80/bu	$28–$35
Radish (Tillage or Forage)	4–10	$1.60–$2.20	$6–$22
Ryegrass (Annual)	30	$0.74–$0.90	$22–$27
Ryegrass (Perennial)	25	$1.66–$2.40	$42–$60
Rye (Winter)	100 (2 bu)	$0.22–$0.38	$22–$38
Sudangrass	80	$0.80–$0.88	$64–$70
Sorghum-Sudangrass Hybrid	35–50	$0.80–$1.40	$28–$70

[1]See Chapter 2 for application rates.

[2]Seed price sources: Albert Lea Seed (MN), Green Cover Seed (NE), Welter Seed & Honey Co. (IA).

the end-wall material, number of poly layers, added supports, door-type, venting system, fans (for cooling and increased air circulation), solar panels, heating systems, and exclusion netting, are usually not included in base model price estimates. While these features require an additional upfront expense, they can potentially save on management, heating, chemical, and other costs. In the past the Natural Resource Conservation Service (NRCS) has offered cost sharing and reimbursement programs for high tunnel construction. Contact your local NRCS office to learn more.

Greenhouses

The cost of the frame and glass paneling can run as high as $20/square foot. You may also need to purchase concrete floor pads and benches. Polycarbonate is sometimes used as an alternative to glass and is less expensive per square foot.

Labor Costs & Management

Labor is required for crop establishment, management, harvesting, customer service, marketing, and public relations. Labor costs are usually the largest expense associated with strawberry production, and modifications that reduce labor needs can therefore have meaningful impacts on profitability.

Strawberry producers use a variety of labor sources, including part-time, full-time and salaried employees, and/or seasonal workers. In certain locations and economic periods, there can be a shortage of willing and capable workers, and since field work is very physical, staffing field positions can be particularly difficult. This is one reason why many farms participate in the H-2A program for temporary agricultural workers in the United States (see H-2A Program) or the Seasonal Agricultural Worker Program (SAWP) in Canada.

Labor Costs

The **true hourly cost** of hired labor includes hourly rate or salary plus social security, workers' compensation, unemployment insurances, additional benefits, and any other obligations. Table 14-4 and the 'Hourly Labor Cost' table (on the *Key* tab in the downloadable workbook) are provided to assist with calculating the total per hour cost of labor to the business. While a total cost per hour example is provided (Table 14-4), be sure to use the tax rates, workers' compensation, and other expenses relevant to your business. These rates will be influenced by your state, the number of employees, pay rate, and the benefits you offer.

When using Downloadable Workbook, other costs associated with a benefit package can be added in the 'Health Insurance/Other' column of the Key tab. Adjust these costs to a per hour rate. This might include contributions to:

- Health insurance: if the business provides health insurance to employees, it may choose to contribute to the premium.
- Retirement plans: there are multiple options for offering savings opportunities to employees, which may or may not include employer contributions.
- Noncash benefits: common noncash benefits include on-farm housing, utilities, meals, transportation to/from employee's home, or education opportunities.
- Reimbursements: including gas, insurance, etc. for use of a personal vehicle on-farm.

Report labor costs (hourly paid labor used for strawberry production) on the *Preplant & Planting Year(s)* and *Bearing Year(s)* worksheets. Fixed labor costs for management and salaried positions should be accounted for on the *Overhead Costs* worksheet because these labor costs should be distributed among all enterprises.

The H-2A Program

The H-2A program is an employer-sponsored work program in the U.S. for temporary foreign agricultural workers and is used by many farms. In the year 2020, over 600 agricultural businesses in the Northeast (ME, NH, VT, NY, MA, CT, and RI) participated in the program. The program is well-suited to the seasonal nature of agricultural crop production and has been a vital resource for many farms that need a reliable workforce and struggle to hire domestic agricultural laborers. Many H-2A workers return to the same farms for decades, making for a stable, knowledgeable, and well-trained workforce.

The H-2A program is highly regulated by multiple agencies. Employers must meet many requirements, including providing no-cost housing, transportation to and from work, adequate kitchens or meals, the cost of travel from the workers' home countries, and more. The Department of Labor sets the hourly rate for H-2A workers at the Adverse Effect Wage Rate (AEWR), which is higher than the federal minimum wage and is set at the state level. At the time of this publication, the New Hampshire AEWR is more than double the minimum wage. There are specific laws governing income tax and FICA withholdings for foreign agricultural workers with an H-2A Visa. Consult with an H-2A payroll specialist and/or the Internal Revenue Service about deduction requirements and policies.

To begin the H-2A process, employers must submit an employment certification form to the Department of Labor. It is common to use a labor contractor who is familiar with the program to assist with the application process. With increased demand for seasonal workers across theUS, new companies that specialize in managing the H-2A process are appearing. Consult other participating farms and your state's employment department for insight and guidance.

Canada has a similar program, called the Seasonal Agricultural Worker Program (SAWP), that allows employers to hire temporary foreign workers. To participate, employers must submit a Labour Market Impact Assessment (LMIA) application and all other

Table 14-4. The true cost per hour of labor to the business includes more than the base hourly rate. This table gives several examples using current tax rates for New Hampshire. When calculating your own labor costs, first check with your state labor department about current tax rates and confirm the cost of your workers' compensation insurance.

	Cost per hour							Total Cost per Hour of Labor
Position	**Pay rate**	**FICA Taxes**		**Federal Unemploy Tax**[1]	**State Unemploy Tax**[2]	**Workers' Comp. Ins.**	**Health Ins. / Other**	
		Social Security (6.2%)	**Medicare** (1.45%)					
Hourly (example)[3]	$20.00	$1.24	$0.29	$0.20	$0.16	$2.00	$3.13	$27.02
Hourly, median (national)[4]	$13.11/hr							
Hourly, average (Northeast)[5]	$15.07/hr							
Salary supervisory[4]	$47,580/yr							
Temp. agricultural employees (H-2A)[6]	$14.99/hr	EXEMPT	EXEMPT	EXEMPT				

[1]The current Federal Unemployment Tax is 6% but only applicable to the first $7,000 employees make each year.

[2]State Unemployment Tax and the taxable wage base varies significantly by state, with current tax rates ranging from 1%-4% in the Northeast region.

[3]Example assumes 2,080 hours worked annually. Federal Unemployment Tax is calculated on the first $7,000 earned at a rate of 6% but is distributed amongst all hours worked. New Hampshire State unemployment tax uses a taxable wage base of $14,000 and a rate of 2.4% and is also distributed amongst all 2,080 hours. Workers Compensation assumes a rate of 10%. Health insurance/other assumes employer contribution of $500/month.

[4]Median compensation as reported by the U.S. Bureau of Labor Statistics (2019) for Farmworkers and Laborers (Crop Production) and Supervisors of Farm Workers.

[5]Rate farm operators paid their hired workers, as reported by the USDA National Agricultural Statistics Service Farm Labor Report for the Northeastern Region (2020).

[6]2020 Adverse Effect Wage Rates for most northeastern states (ME, NH, VT, NY, MA, CT, and RI). Consult with the IRS and a H-2A specialist regarding deductions for H-2A workers, as many workers may have to pay income tax and may request taxes be withheld to reduce potential tax liability at the end of the year.

supporting documentation to the Employment and Skills Development Canada/Service Canada. More information can be found here. There are several significant differences between SAWP and the U.S. H-A program.

Tracking Labor Hours

The labor hours that are needed for strawberry production will be influenced by available machinery, farming practices, the distance between fields, and many other factors. It is best to record how long it takes to complete tasks on your farm, even if this is done informally and only occasionally. This information has multiple applications—by understanding the labor costs of production, you can identify opportunities to increase efficiency. This practice also establishes an average "time to complete" for each task, which can serve as a metric for workers and aid in planning. Remember that the same task may take more or less time depending on the age of the planting and the time of year. For example, runner removal can be quick when plants are young and there are few tender runners, but may take 2–3 times as long if there are more mature runners present.

To track labor costs, provide a crew leader with the printable worksheets in this guide, a notebook, or a phone for recording and sharing activities. The crew leader should record the time spent on each task, the number of employees on site, the name of the field being worked in, and any other useful notes such as weather or pest and disease observations. Encourage workers to note when a task took a particularly long or short amount of time and why to improve the accuracy of your budgeting efforts.

Estimating Harvesting Rate

Harvesting is an important job. Pickers must be trained to properly handle fruit and to harvest only marketable fruit at the proper stage of ripeness. The rate at which pickers harvest is affected by fruit size, canopy density, fruit quality, and the skill and experience of the picker. Fruit characteristics that impact harvesting speed are determined by variety, production system, management, and the age of the planting. Larger fruit will fill a container faster than smaller fruit and harvesting will be quicker. Varieties with open canopies and longer flower trusses make fruit more obvious and accessible during picking, and plants growing on raised plastic-mulched beds typically have runners removed, increasing air flow and fruit visibility. Similarly, rain or hail reduces the percentage of marketable fruit and increases the number of labor hours needed to remove cull fruit or find marketable fruit for sale. Keep records of the fruit yield and labor hours for each harvest.

Picking efficiency estimates range widely: in North Carolina, some strawberry budgets assume a picking rate of 60 lbs/hour, or 1 lb/minute. However, southeastern growers fall-plant, use plastic mulch, and treat plantings as an annual crop, so there is little crown competition and larger fruit. These picking conditions are most (though not entirely) like the first bearing year of plasticulture production in the Northeast. Estimates in the Northeast range from as low 18 lbs/hour (0.30 lbs/minute) to 160 labor hours per acre, or 37.5 lbs/hour (0.625 lbs/minute) assuming the crop yielded 6,000 lbs/acre. Until on-farm data are available, a reasonable estimate for northeastern production is 30 lbs/hour (0.50 lbs/minute). At this rate, an annual yield of 6,000 lbs/acre would require 200 labor hours for harvest. Assuming there are 10 harvests/season, one could estimate 20 labor hours/harvest/acre.

As fruit yields increase, so will harvesting labor costs. The above scenario assumes 6,000 lbs/acre, which is the average yield reported in regional surveys. However, plasticulture production should yield closer to 10,000–15,000 lbs/acre. Maine growers have reported 20,000 lbs/acre from June-bearers on plastic, and research across the region indicates marketable yields from day-neutral varieties grown on plastic mulch ranges from 7,000–20,000 lbs/acre in the planting year, followed by 1,000–9,000 lbs/acre in the spring of the second year after plants are overwintered (second-year yield is highly dependent on variety; see updated recommendations for your area for overwintering day-neutral varieties).

Retaining Labor

Since most activities related to strawberry production require hired labor and many farming businesses struggle to find and retain good workers, it is important to create an environment where people want to continue working. High employee turnover is associated with reduced organizational performance, lost productivity, and significant costs for finding, interviewing, and training new staff. Employers should calculate their turnover rate (including both voluntary and involuntary staff departures) and take active steps to identify and address the reasons behind turnover to retain high-performing employees.

$$\text{Turnover rate} = \frac{\text{\# employees who left (voluntary) or were dismissed (involuntary)}}{\text{total employees at the beginning of year}}$$

Major contributors to turnover are poor initial selection decisions by the business, insufficient training, inadequate or insensitive performance reviews, and inadequate compensation. While it may be tempting to blame high turnover on compensation alone, research shows that pay is not usually the leading cause. Instead, across industries, surveys show that top reasons for voluntary turnover include lack of opportunities for development or promotion, feeling that one's voice is not heard, work-life balance issues, healthcare benefits, and lack of recognition. Thus, while pay is a factor, it's not the only one.

Many of the abovementioned turnover drivers can be controlled by the business, and research shows that small and medium-sized businesses are uniquely positioned to offer non-financial rewards that are very appealing to job seekers. These include flexibility, recognition, training/development opportunities, positive relationships with supervisors, equitability in compensation and promotions, feelings of trust, value and involvement, and an overall positive work environment.

Flexibility, in particular, is a unique strength of small business, which can adapt more nimbly than larger organizations to changing employee needs. Small efforts, such as offering condensed work weeks, extra time off, and flexible schedules, can go a long way with employee or prospective employee. Furthermore, regular interaction between business owners and staff strengthens employer-employee relationships and gives owners/managers valuable insights into their employees' work/life situations—allowing for quick accommodation. Smaller organizations can also improve operations by soliciting insights from their workers. Research shows that some of the best suggestions for improving operations and increasing efficiency have come from those working in front-line roles. Thus, eliciting and listening to staff members' ideas is a win-win for both employees and the company.

When it comes to training and development, providing these opportunities does not need to be costly. Consider offering employees attendance at Extension education and training events, entry to special seminars and association meetings, or holding in-house educational events. Encourage discussion and sharing amongst staff. Continued education in crop management empowers field workers to identify issues and better understand why certain practices are necessary.

Altogether, when managers offer flexibility, value employee input, and provide opportunities for professional development, they signal to their staff that they value their expertise and want to help them fulfill their potential. This creates a sense of shared commitment that benefits the business and leads to a better work environment and lower turnover rate.

Using a Professional Employer Organization

Small businesses can benefit from using service providers to process payroll, track hours, manage benefits, keep up with regulations, and more. One such service is a professional employer organization (PEO). PEOs allow employers to outsource necessary services for managing and providing benefits to employees, including human resource support, payroll, tax filing, workers' compensation insurance, health benefits, compliance issues, crop insurance, paperwork, and more. Administrative fees usually range from 2–4% of a company's payroll, which is often less expensive than the cost of having a dedicated administrator on staff. Furthermore, PEOs offer expertise in human resources and other fields that can help protect the company. Since PEOs work with many businesses, it may also be possible to purchase benefits and insurances at a lower cost.

Before entering a relationship with any PEO, it is very important to be aware of the legal implications of that relationship. One arrangement is for PEOs to become a "co-employer of record" with the client business, which means that for tax purposes, the PEO is the legal employer. This can have significant implications for the business and should be well-investigated. Administrative services organizations (ASOs), human resource outsourcing (HROs), and other staffing firms differ from PEOs in this regard. These firms simply provide services, such as human resources or payroll, and the employer of record does not change.

Before signing any agreement with a PEO, ASO, HRO, or other firm, be sure you understand the legal arrangement, how liability is allocated, what the farm's obligations are, and what services you will receive (and when). Ensure that the service provider will solve the problems your farm is trying to address and that you understand when and how often the farm can use the service and how information will be exchanged.

Employers who are part of the H-2A program should find a service provider who works in this space, as payroll and legal considerations differ.

PREPLANT PERIOD

Instructions: For each relevant task, fill in the quantity and price of materials, rate of labor, and machine hours required. Calculate total cost (gray columns) and transfer them to the *Income Statement* in the "Preplant Period" column.

		MATERIAL COSTS			LABOR COSTS			MACHINERY	
Activity	Notes/Records	Qty	Price	Qty x Price =	Hours (Qty)	Total Hourly Rate	Hours x Rate =	Machinery Used	Machine Hours
Herbicide application									
Plowing									
Disc harrowing #1									
Rock picking									
Soil sample collection and test submission	$20/test (marco, pH, OM); $8/shipping								
Lime application	$55+/ton delivered (not spreead); ton/acre rate will depend on soil test and lime product								
Disc harrowing #2									
Dragging									
Cover cropping	Seed cost of $15-$70/acre								
PREPLANT PERIOD TOOLS			MATERIALS ($):			LABOR($):		MACHINE HRS:	

PLANTING YEAR

Instructions: For each relevant task, fill in the quantity and price of materials, rate of labor, and machine hours required. Calculate total cost (gray columns) and transfer them to the *Income Statement* in the "Planting Year" column.

ACTIVITY	NOTES & AVG. COST	MATERIAL COSTS			LABOR COSTS			MACHINERY	
		Qty	Price	Qty x Price =	Hours (Qty)	Total Hourly Rate	Hours x Rate =	Machinery Used	Machine Hours
Plowing									
Disk harrowing #1									
Fertility/amendment application	$20-$40/25# bag (varies)								
Nitrogen source									
Potassium source									
Compost/amendments									
Disc harrowing #2									
Dragging									
Laying/shaping beds	Seed cost of $15-$70/acre								
Drip irrigation	Single Line: $140 (8 mil)-$175 (10 mil)/ acre								
Plastic mulch									
Planting									
Total labor hours required									
Bare-rooted plants	$0.14-$0.12/plant (variety and quantity dependent) + shipping								
Plug plants	$0.27-$0.50/plant + shipping								
Planting tools	$14 ea.								
Irrigation Setup									
Header hose	$0.20/foot ($25/acre [20 rows])								
Header hose connectors	$0.40 ea. (no valve) and $1.50 ea. (on/off valve); ~$8/acre								
Dripline repair couplers	$0.50 ea.								

Filter and/or pressure regulator									
Setup irrigation system									
Test irrigation sytem									
Labor for making repairs									
Run irrigation/fertigation	Include the total number of irrigation events.								
Soluble fertilizer									
Flower removal									
Runner removal	Recommended 1-2x/month								
Hand weeding	Include the number of times per season								
Cultivation	Include the number of times per season								
Landscape fabric or weed mat	$1,200/acre								
Leaf tissue analysis	$30/test								
Scouting for pests/pathogens									
Harvest preperation									
Harvest	Consider the number of har-vests/season. Average rate of 30 lbs/hour (0.50 lbs/minute) = 200 labor hrs/acre (for a 6,000 lb crop), or 20 hrs/harvest (as-suming 10 harvests/season)								
Quart containers	$0.12–$0.23 ea.								
Pint containers	$0.07–$0.23 ea.								
Flats or trays	~$0.60 ea.								
Gloves	$10/100-glove box								
Flags	$8/100 flags								
Harvest cleanup									
Side dressing applications	Add fertilizer costs.								
Application 1:									
Application 2:									
Application 3:									

Herbicide application	Add chemical & surfactant.								
Application 1:									
Application 2:									
Application 3:									
Application 4:									
Pesticide applications	Add chemical & surfactant.								
Application 1:									
Application 2:									
Applications 3:									
Application 4:									
Fungicide applications	Add chemical & surfactant.								
Application 1:									
Application 2:									
Application 3:									
Application 4:									
Protected culture structures									
Commercial low tunnel hoops	~$7.75 ea., $11,250/acre								
Low tunnel film	$2800/acre								
High tunnel film									
Removal/storage of irrigation									
Straw application	$1,200/acre (174 bales @ $7)								
Rowcover application	Single layer: $1,200 (0.9 oz);$1,600 (1.2 oz)								
Sandbogs	39/100 bags + sand for filling								
Deer fencing									

PLANTING PERIOD TOTALS: **MATERIALS ($):** ______ **LABOR($):** ______ **MACHINE HRS:** ______

BEARING YEAR

Instructions: For each relevant task, fill in the quantity and price of materials, rate of labor, and machine hours required. Calculate total cost (gray columns) and transfer them to the *Income Statement* in the "Bearing Year" column. Two Bearing Year columns are provided in the case that the planting is kept for two years.

ACTIVITY	NOTES & AVG. COST	MATERIAL COSTS			LABOR COSTS			MACHINERY	
		Qty	Price	Qty x Price =	Hours (Qty)	Total Hourly Rate	Hours x Rate =	Machinery Used	Machine Hours
Winter protection removal									
Frost protection									
Setup/install									
Run frost protection									
Recover/remove rowcover									
Runner removal	Recommended 1–2x/month								
Irrigation setup									
Header hose	$0.20/foot ($25/acre [20 rows])								
Header hose connectors	$0.40 ea. (no valve) and $1.50 ea. (on/off valve); ~$8/acre								
Dripline repair couplers	$0.50 ea.								
Filter and/or pressure regulator									
Setup irrigation system									
Test irrigation system									
Labor for making repairs									
Run irrigation/fertigation	Consider the number of irrigation events.								
Soluble fertilizer									
Hand weeding									
Cultivation									
Landscape fabric or weed mat									
Leaf tissue analysis									

Scouting for pests/pathogens									
Harvest preperation									
Harvesting	Consider the number of harvests/season. Average rate of 30 lbs/hour (0.50 lbs/minute) = 200 labor hrs/acre (for a 6,000 lb crop), or 20 hrs/harvest (assuming 10 harvests/season).								
Quart containers	$0.12–$0.23 ea.								
Pint containers	$0.07–$0.23 ea.								
Flats or trays	~$0.60 ea.								
Gloves	$10/100-glove box								
Flags	$8/100 flags								
Harvest cleanup									
Mowing									
Narrowing or rows									
Side dressing applications	Add fertilizer costs.								
Application 1:									
Application 2:									
Application 3:									
Herbicide applications:	Add chemical & surfactant costs.								
Application 1:									
Application 2:									
Application 3:									
Application 4:									
Pesticide applications	Add chemical & surfactant costs.								
Application 1:									
Application 2:									
Application 3:									

Application 4:							
Fungicide applications	Add chemical & surfactant costs.						
Application 1:							
Application 2:							
Application 3:							
Application 4:	~$0.60 ea.						
Protected culture structures							
Commercial low tunnel hoops	~$7.75 ea., $11,250/acre						
Low tunnel film	$2800/acre						
High tunnel film							
Removal/storage of irrigation parts							
Straw application	$1,200/acre (174 bales @ $7)						
Rowcover application	Single layer: $1,200 (0.9 oz); $1,600 (1.2 oz)						
Sandbags	$39/100 bags + sand for filling						
Deer fencing							

BEARING PERIOD TOTALS: **MATERIALS ($):** **LABOR($):** **MACHINE HRS:**

OVERHEAD & FIXED COSTS

Instructions: Common overhead and fixed costs are listed below. Once a total value is determined, allocate a portion to the strawberry crop for each production period on the Income Statement. This can be done by distributing these costs proportionally based on acreage.

Machinery costs are not listed but there is a line item on the Income Statement to account for operating and ownership costs associated with machinery that should be allocated to the planting being evaluated. The Downloadable Workbook provided in this chapter provides an easy-to-use Machinery Costs calculator.

Expense	**Total Annual Farm Overhead**
Land rentals	
Mortgages	
Real estate taxes	
Insurance	
Vehicle	
Farm policy	
Heating (greenhouse, headhouse, work rooms, etc.)	
Utilities	
Electricity	
Cell phones	
Landlines	
Internet	
Other	
Office staff salaries: Human resources, Accounting, etc.	
Management salaries	
Owner(s) salaries	
Office supply expenses	
Accounting services	
Payroll services	
Human Resources services	
Legal or other professional services	
Service providers such as PEO's, etc.	
Time keeping subscriptions/services	
Advertising/marketing	
Memberships	
Subscriptions	
OVERHEAD TOTAL:	

INCOME STATEMENT

Instructions: Carry over the total material, labor, and overhead costs from the previous sheets for each period (preplant, planting, and bearing years).

Revenue	**PREPLANT PERIOD**	**PLANTING YEAR**	**BEARING YEAR1**	**BEARING YEAR 2**
Total marketable yield harvested during each period (lbs):				
Total revenue ($): (marketable yield x price/lb) Include revenues from wholesale, retail, and pick-your-own.				

Expenses

Total materials costs:				
Total labor costs:				
Total overhead:				
Other misc. costs:				
Machinery ownership costs (insurance, interest, and depreciation)				
Machinery operating costs (lube, fuel, repairs)				
Total Costs:				

Profit/Loss

Profit for each period (total revenue - total costs) =				

Cumulative profit/loss value (add all periods together) =	

Break-even price (cumulative profit/loss value divided by marketable yeild for all periods combined) =	

Further Reading

Cornell Berry Budgets

Farm Financial Management Reports and Analyses, developed by University of New Hampshire Extension. This free and downloadable Excel workbook is thorough but user-friendly. The user fills out information on owner draws, labor hours and costs, and cash flow and a cash flow statement, beginning and end-of-year balance sheets, and an income statement are automatically generated.

New England Farm Account Book, developed by the University of Maine. This free downloadable Excel workbook can be used for bookkeeping, including keeping track of receipts, expenses, and labor, and for generating profit monthly profit/loss reports and crop-specific profit/loss calculations.

North Carolina State University Budgets/Cost Estimates. Organic budget available.

PennState Extension Budgets. Matted row and plasticulture budgets for planting and production years.

The Organic Farmer's Business Handbook. Richard Wiswall's book provides detailed guidance on how to operate a farm profitably and has been useful to many growers in the region:

Northeast Organic Farming Association of Vermont (NOFA-VT) has assembled many enterprise budgets on common vegetable and other resources for measuring costs.

Legal Guide for New Hampshire Agriculture Producers

U.S. Department of Labor O*Net Online held create accurate job descriptions for any role.

Adverse Effect Wage Rates. Department of Labor.

Foreign Agricultural Workers on H-2A Visas. Internal Revenue Service.

Federal Income Tax and FICA Withholding for Foreign Agricultural Workers with an H-2A Visa (Factsheet). Internal Revenue Service.

Canadian Seasonal Agricultural Work Program

Low Tunnel Strawberry Production Guide

CHAPTER 15

Diagnosing Problems in Strawberry

A successful grower must be able to detect problems in the strawberry planting; however, diagnosing the issue can be challenging due to the number of possible contributing factors (fungi, bacteria, insects, viruses, nematodes, nutritional deficiencies, nutrient toxicities, herbicide injury, physiological disorders, genetic abnormalities, weather anomalies). A single specimen or photograph is usually insufficient to make a diagnosis since many disorders share common symptoms. For example, wilting leaves can be caused by an anthracnose lesion on the leaf petiole or by insect larvae feeding on the roots. Similarly, yellow leaves may be evidence of either nutrient deficiency or herbicide drift, and crinkled leaves can result from both cyclamen mite and frost. Diagnostic labs look for evidence of disease, but they may not be able to diagnose a problem that is not caused by a bacteria, virus, or fungi. On the other hand, foliar testing can determine if a nutrient is deficient but cannot detect the presence of pathogens. Before choosing where to send the sample for study, a grower must have a good idea about the source of the problem.

Following the steps in this guide can help determine what might be causing unusual symptoms in a strawberry field. Once a suspected cause has been identified, information in the supplementary chapters can be used to confirm the diagnosis and determine how it can be treated.

STEP #1: Is the symptom "normal" or problematic?

Growers need to know how a strawberry plant should look throughout the year to be able to identify when something unusual is happening. For example, June-bearing strawberries should produce runners in August. If runnering is sparse, then something may be wrong. But knowing how many runners should be present is critical to knowing if something is "off." Inexperienced growers can build this knowledge through careful observation and record keeping.

Well-watered strawberries will excrete droplets of water along the edges of leaves on humid nights. This phenomenon, called guttation, indicates that plants have sufficient moisture. An inexperienced grower may be alarmed to find that the strawberries are leaking water, but this is a normal and positive sign. Under conditions of sunny days and cold temperatures in fall, strawberry leaves may turn bright red. This occurs when green chlorophyll breaks down leaving other leaf pigments to predominate. This color change is stronger in some years than others, but is normal.

STEP #2: Take careful notes

Recognizing when symptoms first appear in relation to weather, fertilizer applications, or pesticide applications is a powerful tool for figuring out what could be wrong. The time between extreme weather or pesticide applications and the onset of symptoms can validate or eliminate possible causes. It is therefore important to keep a record of pesticide and fertilizer applications as well as notable weather events.

For example, applying a pesticide when weather is cloudy and cool may not be problematic, but the same application on a hot, sunny day can cause phytotoxicity. Leaf damage that appears a day or two after pesticide application is likely associated with that pesticide, especially if the weather was hot and sunny during or just after the application. If the last pesticide application was two weeks before the onset of leaf symptoms, then the two are likely unrelated. Problem diagnosis is just one reason among many to keep a written record of farming practices and observations.

STEP #3: Note patterns in the field

The pattern in which symptoms appear in the field can help identify the cause of a problem. If symptoms are aligned with changes in soil type, it may be a nutrient or herbicide injury problem as these issues often follow soil patterns. Pathogens are another possible cause, as heavier soils may have poor drainage that can create a favorable environment for pathogen proliferation in root systems.

Symptoms can also follow topography. If symptoms appear at the bottom of a swale, the issue may be accumulation of water or cold air resulting in damage to the plant. Damage at the top of a swale in a site with sandy soils may indicate insufficient water.

Insect pests often migrate into a strawberry field from the edges. If the problem is caused by strawberry clipper and tarnished plant bug, damage will be concentrated toward the edges of the field.

Symptoms associated with a particular variety, but not others, may indicate a pathogen since susceptibility or resistance to disease differ across varieties.

Damage from sprays tends to create regular patterns, such as every fourth row from sprayer overlap, or damage near the edge of a field where a sprayer slowed to turn. In new plantings, symptoms that occur in batches of 25 plants suggest that plants were not stored properly prior to planting (since plants come in bundles of 25).

Random patches of damage are unlikely to be caused by herbicides or nutrient deficiencies but are common with viruses. Virus symptoms and root diseases typically appear in the same location in the same planting year after year, whereas insect damage may appear one year but not the next.

Conversely, short-term weather events can result in visible effects of damage at only one developmental stage. For example, flowers damaged (but not killed) during a frost or freeze event can cause misshapen fruit throughout the field, while later fruit are not misshapen at all because buds weren't as vulnerable during the cold event.

STEP #4: Note patterns on the plant itself

Identify the source of the damage in the plant. Start at the top and work down: damage is usually located at the lowest place where symptoms begin. A wilting leaf may be caused by a lesion on the petiole or by damaged roots. Aboveground symptoms often reflect belowground damage. It is easy to dig up a strawberry plant, so inspect the roots whenever the plant is wilting or lacking vigor. The absence of white root hairs or the presence of blackened roots suggests that the plants are not healthy.

Younger leaves may show symptoms before older leaves. Cyclamen mites damage new leaves as they emerge. Symptoms of herbicide misapplication, particularly preëmergent herbicides, often first appear in young leaves. Certain nutrient deficiencies when the nutrient is not mobile in the plant (e.g., iron, calcium) will also affect younger leaves first. In contrast, mobile nutrients such as nitrogen and potassium will move to the growing leaves and out of the older leaves so only older leaves show symptoms. Burn-down herbicides that are not translocated will express symptoms on all leaves, but the newest emerging leaves will be less impacted. Verticillium wilt symptoms affect the oldest leaves, often leaving the older outer leaves intact. Verticillium wilt damages the roots, not the leaves.

Certain patterns of damage on a leaf suggest particular causes. Magnesium deficiency symptoms appear between veins, as do certain preëmergent herbicides (e.g., simazine). Other herbicides express symptoms along veins (e.g., terbacil). Calcium deficiency symptoms occur at the tips of leaves. Potassium deficiency and excess fertilizer or salts in water cause burning along the leaf margins.

STEP #5: Confirm the diagnosis

Tests are available for viruses, nematodes, and nutrients. Diagnostic labs can culture fungi and bacteria from symptomatic tissue and can often identify the cause by using various selective media. There are no affordable tests for herbicide residues. Cornell University's Berry Diagnostic Tool website (see Further Reading & Citations) is designed to help identify the causes of problems in strawberry fields.

If the cause of the problem is unclear, share the observed patterns with an expert. Most state Extension systems operate plant diagnostic labs; consult with your local lab to determine how best to take a sample that will enable them to help confirm diagnoses.

STEP #6: Take action

Once the cause of the problem is confirmed, determine what sort of action is required. If a pest is below economic threshold, then no action is required other than further monitoring. If a pest is above threshold, or if the damage is increasing at a high rate or will increase due to weather conditions or other factors, then an intervention may be required.

The supporting chapters describe many of the common causes of problems in strawberry plantings and discuss ways to address them. Check local and state regulations before applying pesticides.

Some problems can only be solved by removing affected plants. This is the case with genetic abnormalities and viruses as they are generally systemic within the plant and cannot be eliminated.

Sometimes the solution is to let the plants outgrow the symptoms. This can be the case when an herbicide slightly damages the strawberry plant (e.g., through drift), but does not kill it. Japanese beetle grubs might damage a new strawberry field but not kill the plants. Typically, the damage does not recur in the second year and plants may recover.
It is always a good idea to map any damage to look for patterns year over year. If symptoms reappear the same spot across growing seasons, this narrows down the list of possible causes.

It is always better to prevent a problem than to try to eliminate it once it occurs. Problems are less likely to occur in fields with good soil health, regular soil and leaf tissue testing, and scouting.

Further Reading & Citations

Berry Diagnostic Tool: Strawberries. Cornell University.

CHAPTER 16

Questions and Answers about Pesticide Residues, Organic Production, and Strawberries

In retail businesses, customers may have many questions about agricultural practices and outcomes. These often relate to production methods and
chemical use. Each year, the Environmental Working Group (EWG) issues a list of fruits and vegetables—the so-called "Dirty Dozen". Strawberries often top the list as the commodity with the highest levels of pesticides, causing many consumers to worry about eating strawberries.

The following information may be helpful when in the position of engaging with the public on this issue.

Are pesticides safe?

All pesticides, whether they are naturally-occurring or synthetically derived, can be harmful when they come in contact with the human body in large amounts. However, when applied according to label instructions, pesticide residues will be below legal limits when the crop is harvested. The legally allowable amount of pesticide residue on fruits and vegetables (the "tolerance") is set by the Environmental Protection Agency to be far below levels known to cause physiological effects in humans.

In all cases, the risks of being harmed by pesticides depends on the toxicity of the material and the exposure to the material. Those who apply pesticides must wear protective equipment when applying any pesticide. Repeated long-term exposure to some pesticides can cause health problems.

Many consumers may be concerned about pesticide residues on fruits. Growers should answer consumer questions honestly, emphasizing the safe practices they use. For example, if pesticides are not applied when fruit are present, or the number of pesticide applications are minimized, or only certain types of pesticides are used, these statements may allay concerns.

A recent study[1] that combined toxicological and epidemiological approaches suggested that the health benefits from consuming fruits and vegetables **far outweigh** the risks attributed to the consumption of pesticide residues, as long as regulations are followed.

Do strawberries pose food safety risks?

The greatest health risk from consuming strawberries is from harmful pathogens that spread from human waste or animal manure onto harvested fruit that are then eaten raw. All farms should be using good management practices, such as keeping wild and domesticated animals out of strawberry fields, avoiding contact with raw or unprocessed amendments of animal origin, and maintaining and requiring the use of sanitation facilities for employees and pickers.

Do organic strawberries contain pesticide residues?

Organic growers are allowed to use certain naturally-derived pesticides on strawberries, so it is possible that they contain pesticide residues. As a general rule, however, pesticide levels are lower for organic than for conventionally-grown strawberries.

Pesticide residues on crops vary greatly depending on where a crop is grown, and upon the specific practices used by the grower. For example, strawberries grown in warm, humid climates often receive more pesticide applications than those grown in cooler, drier climates. sold directly to consumers often receive fewer pesticide applications than fruit that must withstand shipping and holding prior to sale.

Do organic strawberries taste better than conventional strawberries?

There's no scientific consensus that organic berries consistently taste better or have higher nutritional content. Many studies[2,3,4,5] have directly compared organically-grown and conventionally-grown strawberries using the same variety on the same farm in replicated trials, and have measured many variables including flavor volatiles, sugars, acids, anthocyanins and antioxidant activity. Results from these experiments have been mixed. Some studies showed no differences, but in others, either conventional or organic berries had higher values. Results varied from year to year and from variety to variety. Organic berries were preferred in sensory ratings in some studies, but not all. This is probably because many factors including temperature, soil moisture, and light exposure influence flavor and nutritional qualities.

Why are organic strawberries more expensive?

Managing weeds without herbicides requires much more labor. Organic sources of nitrogen are slower to break down and are more expensive than conventional sources. Yields tend to be about 30% lower in organic than conventional strawberry farms. Organic farms also need to have longer crop rotations, so need to use more land to grow the same amount of crop. In general, the risks of crop loss are greater without the use of synthetic fertilizers and pesticides. Thus, organic growers need to compensate by increasing the price relative to growers who can use less land- and labor-intensive methods and less expensive inputs.

Why should consumers support their local farms?

Whether conventional or organic, it is likely that fruit were produced in a large-scale operation, often in California or Mexico. In contrast, most farms selling direct to consumers through farm stands, pick-your-own, CSA, or farmers markets are comparatively smaller. For example, in the Northeast, most strawberry farms are small, averaging about 5 acres of berries per farm.

One benefit of purchasing directly from local farms is that it is possible to ask the farmer or farm employees about growing practices and any other information that each consumer views as important. As a grower, consider having a list of talking points, a printed handout, or even signage, describing the practices you use that are good for the environment, good for the community, or good for consumers. Examples might include: incorporating cover crops, minimizing tillage, mulching, and avoiding high rates of fertilizer—all of which are good for soil health. Likewise, minimizing pesticide applications and using integrated pest management (IPM) are good for the environment and consumers.

Further Reading & Citations

1. Valcke, M., M-H. Bourgault, L. Rochette, L. Normandin, O. Samuel, D. Belleville, C. Blanchet, D. Phaneuf. 2017. Human health risk assessment on the consumption of fruits and vegetables containing residual pesticides. Environment International. 108: 63-74.

2. Cardoso, P.C., A.P.B. Tomazini, P.C. Stringheta, S.M.R. Ribiero, H.M.Pinheiro-Sant'Ana. 2011. Vitamin C and carotenoids in organic and conventional fruits grown in Brazil. Food Chemistry 126: 411-416.

3. Camargo, L.K.P., J.T.V de Resende, T.T. Tominaga, S.M. Kurchaidt, C.K. Camargo, A.S.T. Figueiredo. 2011. Postharvest quality of strawberry fruits produced in organic and conventional systems. Horticultura Brasileira 29(4).

4. Hargreaves, J.C., M.S. Adl, P.R. Warman, H.P. V. Rupasinghe. 2008. The effects of organic and conventional nutrient amendments on strawberry cultivation: fruit yield and quality. Journal of the Science of Food and Agriculture 88:2669-2675.

5. Reganold, J.P., P.K. Andrews, J.R. Reeve, L. Carpenter-Boggs, C.W. Schadt, J.R. Alldredge, C.F. Ross, N.M. Davies, and J. Zhou. 2010. PLoS ONE 5(9): 1-14.

Scan the QR code to download a digital copy of the guide and workbook.